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DREDGING ENGINEERING

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FRONTISPIECE: The Admiral—American Dredging Co., Phila., Pa.

DREDGING ENGINEERING

BY

F. LESTER SIMON, B. S. IN C. E.
ASSOC. M. AM. SOC. C. E.

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PREFACE

With the reader's indulgence, we will explain just what this small book is by first defining what it is not. It is not a compendium of statistics. Neither is it a record of the actual performance of specific dredges of all kinds and under all conditions; nor yet a compilation of dredging cost data. Such information is already minutely available in the Annual Reports of the Chief of Engineers, U. S. Army, and in the records of the various departments of commonwealths and municipalities controlling dredging operations in their respective localities.

It has been the author's intention first to describe the principal types of dredge in such manner as to impart a fundamental working knowledge of their construction and operation, and then to consider, in concise form, the usual problems confronting the engineer in the conception and accomplishment of dredging projects.

Because of the fact that most literature upon the subject, having been presented in the form of papers and articles in the technical periodicals, is not only not readily available, but incomplete, in that each as a rule treats only of one particular phase of the subject, it is thought that a need exists for a comprehensive treatise, which should be helpful alike to the student and engineer. To fill this want has been the author's objective.

The importance of the subject, while not always apparent to the layman, is obviously paramount, involving the expenditure of many millions of dollars annually for the necessities of commercial life.

F. L. S.

BALTIMORE, MD.,
April, 1920.

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DREDGING ENGINEERING

PART I

DREDGES

CHAPTER I

DEFINITION AND CLASSIFICATION

A *dredge* is a floating excavating machine, and the process of removing subaqueous material is termed *dredging*.

There are many kinds of dredges and several classifications are possible, differing in the choice of a basis of distinction. It is the author's intention to discuss only the more important types, the usual equipment of to-day, disregarding the older and practically obsolete plant such as *stirring* and *pneumatic* dredges. With this limitation, dredges may be classified broadly under two general heads:

I. *Bucket Dredges*

II. *Hydraulic Dredges*

Bucket Dredges, obviously, are machines that remove the material by means of buckets, which, after obtaining their loads by biting or digging into the bottom, are raised clear of the water to dump either into waiting scows, self-contained hoppers, or upon spoil banks.

Hydraulic Dredges, known also as *Suction* or *Pump* dredges, excavate by direct centrifugal pumping through suction pipe, pump and discharge pipe into hoppers contained in the dredge itself, into hopper barges, into adjacent deep water, or into natural or prepared reservoirs, called *impounding basins*, from which the great volume of water,

necessarily pumped along with the dredged material, runs off, leaving a deposit of solid matter.

The bucket class may be sub-divided into three types:

(*a*) *Grapple Dredges*

(*b*) *Dipper or Scoop Dredges*

(*c*) *Ladder or Elevator Dredges*

Both *Grapple* and *Dipper* machines have a single bucket each. In the former, it is suspended from the end of a swinging boom and consists of two or more shells or jaws, by the closing and opening of which the bucket is loaded and discharged. In the latter, it is a scoop attached to a long handle and "digs" in the same manner as the familiar steam shovel on land.

Ladder Dredges consist of a series of smaller buckets travelling in endless chain succession upon an inclined frame called a *ladder*, in passing under the lower end of which they receive their loads by scraping along and into the bottom, discharging into a chute while passing over the upper tumbler. Apparently it is simply an application of the old principle of the bucket elevator.

Grapple or *Grab Dredges*, in turn, may be divided into two sub-types:

(*a*) *Clam-shell Dredges*

(*b*) *Orange-peel Dredges*

A distinction only by virtue of the style of bucket carried. A clam-shell bucket has two quadri-cylindrical shells arranged in a manner sufficiently analogous to those of the more humble clam to warrant the pilfered title. An orange-peel bucket has generally four shells, forming a hemispherical bowl when closed, but spreading when open like the quadrants of an half orange.

Ladder Dredges are susceptible of sub-division into three classes:

(*a*) *Stationary Dredges*

(*b*) *Self-propelled, Barge-loading Dredges*

(*c*) *Sea-going, Hopper Dredges*

The first is the usual river or calm-water type, which is fed laterally or radially by means of anchorages or spuds

and hauling cables, and discharges either into waiting barges, or into deep water or spoil basins more remote from the dredge.

Both the second and third types have moulded hulls and sea-going qualities, but the second, because of the accompanying barge, is confined to the calmer waters of ports and estuary channels, while the third is a sea-going vessel, comprising both barge and dredge in one.

Hydraulic Dredges are of two general types:

(*a*) *The River Dredges*

(*b*) *Sea-going Hopper Dredges*

There are two principal *River Types*:

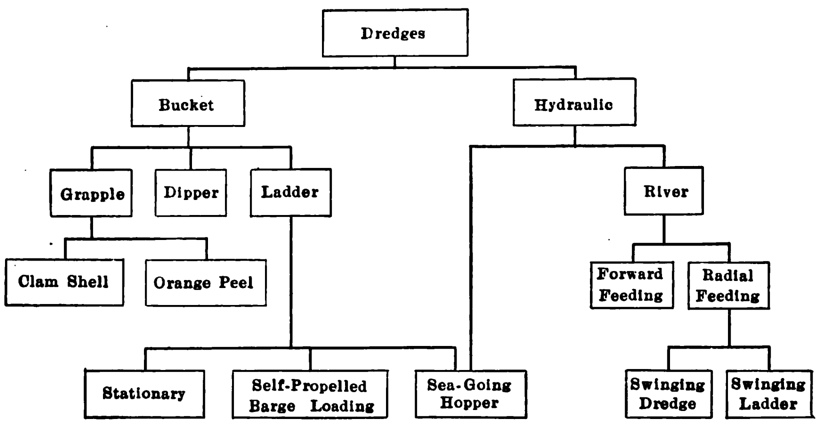
(*a*) *Radial Feeding with Spud Anchorage*

(*b*) *Forward Feeding or Mississippi River Type*

Again, *Radial Feeding Dredges* may be either of the *Swinging Dredge Type* or the *Swinging Ladder Types.* In the former, the dredge itself pivots about a stern spud, and in the latter, the ladder only pivots about the bow of the dredge, which is held stationary by four spuds.

The subdivision of *Hydraulic Dredges* might be carried still further with self-propulsion as the distinguishing feature, as both Radial and Forward Feeding Machines have been built to navigate under their own motive power. They, however, are the exception rather than the rule and would result in unwarranted complication of the above.

The entire classification may be summarized as follows:



CHAPTER II

GRAPPLE DREDGES

General Description.—A grapple dredge is, in principle, a derrick mounted on a float and swinging a grab bucket. Any derrick lighter may perform the operation of dredging by simply attaching a grab bucket to its fall. This, however, is merely a makeshift, and by no means constitutes a dredge. The operation of the bucket is but one of three principal functions of the grapple necessary to the complete business of "mud-digging." They are:

1. To operate the bucket
2. To control the position and local movement of the dredge itself
3. To handle the scows

The first requires a derrick, comprising boom, "A" frame and back legs and the requisite hoisting machinery, consisting of a double cylinder, double drum engine with boiler, auxiliaries and appurtenances. The bucket is a very important machine in itself, and its proper design is most essential to the efficiency of the dredge. It will be discussed in detail subsequently. It is hung from the end of the boom by two wires or chains by means of which it is raised, lowered, opened and closed and by which also the boom is swung.

The position and local movement of the dredge is controlled by spuds, by anchors, or a combination of both. Spuds are long timbers of heavy section suspended from tall masts or so-called gallows-frames and running vertically through openings in or pockets attached to the hull. They are raised by hoisting engines and, when released, penetrate into the river bottom by virtue of their own weight, thus anchoring the hull and holding it in position while digging.

Fig. 1.—The Camden—American Dredging Co., Phila., Pa.

The third function, that of handling the scows, is accomplished by three wires attached to the scows and lead to capstans or to hoisting engines on the deck of the dredge. The scow is thus moored to the starboard quarter of the dredge and, as each pocket is loaded, is hauled aft until the next pocket comes under the bucket.

Figure 1 is a first-class representative grapple, the Dredge "Camden," a 7½ yard clam-shell, of the American Dredging Company of Philadelphia, shown working for the American International Shipbuilding Corporation in the construction of the Hog Island Shipyard on the Delaware River.

For convenience, in a more detailed exposition of the grapple dredge, each component part will be discussed successively as follows:

1. *The Bucket*
2. *Boom, "A" frame and Back Legs*
3. *Spuds, Spud-wells and Gallows-frame*
4. *The Machinery*
5. *The House*
6. *The Hull*

The Bucket.—The grapple dredge bucket, or the *grab* bucket as it is called, is of two kinds, the *clam-shell* and the *orange-peel*, as briefly defined in the foregoing classification. Both have the same principle of operation, but differ in that the clam-shell has two jaws or shells while the orange-peel has three or four. There are two principal types of clam-shell bucket, the *common* type and the *sliding cross-head* bucket, each of which may be distinguished further as a *hard*, *medium* or *soft-digging* bucket according to the class of material for which it is designed. Figure 2 is a soft-digging clam-shell of the common type.

A hard-digging clam-shell bucket of the sliding cross-head type with a capacity of 7½ cubic yards, is shown in Fig. 1 and the frontispiece.

Figure 3 is the extra heavy, standard orange-peel bucket of the Hayward Co.

The Common Grab.—A general knowledge of the construction and operation of grapple buckets may be had by an analysis of the common grab.

The bucket has five main constituent parts as shown in the outline drawing, Figure 4.

1. The two shells *a*
2. The spool and shaft *b*
3. The four arms *c*
4. The cross-head *d*
5. The two closing chains *e*

FIG. 2.—Soft-digging clam-shell bucket of the common type. (*Courtesy of Vulcan Iron Works, Inc., Jersey City, N. J.*)

The shells rotate about the main shaft, to which the spool is keyed. The spool consists of a large central sheave to the perimeter of which the closing wire *f* is attached, and two cylinders of smaller diameter, (the spools proper) to which the two closing chains *e* are fastened.

Whether a single casting or independent parts, these three wheels are keyed to the main shaft. The arms are pin connected to both cross-head and shells. The upper ends of the closing chains e are attached to the under side of the

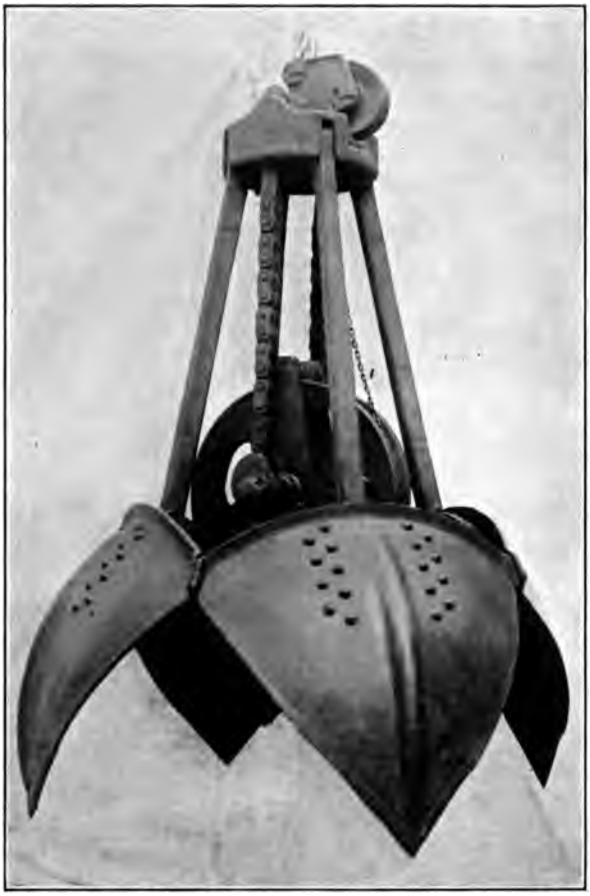


FIG. 3.—Extra heavy orange-peel bucket. *(Courtesy of the Hayward Co.)*

cross-head d. The closing wire f is confined by a lead sheave g mounted on the side of the cross-head. The opening wire h is bridled to the cross-head.

Obviously, therefore, if the bucket is suspended from the opening wire with the closing wire slack, the spool and shells fall by virtue of their weight until the spool has

rotated to the point at which the closing chains are vertical and taut, preventing further motion. The bucket is hanging open. If, now, the closing wire is given the load, and the opening wire slacked, the central sheave is caused to rotate so that the spools proper are rolled up on the closing chains toward the cross-head until the bucket's jaws come together. The bucket is closed. The limit of tension in either opening or closing wire is the weight of the loaded bucket in air, plus an allowance for impact and

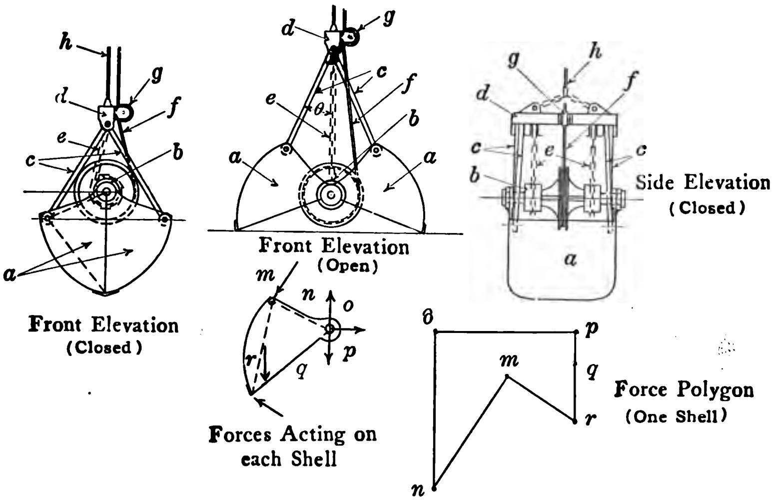


FIG. 4.—The common grab bucket.

breaking bottom suction. With the bucket resting open upon the bottom, however, the closing wire tension at the beginning of the "bite" is necessarily less than the weight of the submerged bucket empty since the bucket obviously would be raised clear of the mud by a pull greater than its weight. As the bucket closes, the weight of the enclosed material becomes effective and the wire tension increases. The total stress in the two closing chains is equal to the product of the closing wire tension by the ratio of the diameter of the central sheave to that of the chain spools. The total compression in the four arms is equal to the sum of the total closing chain tension and the weight of the

cross head divided by the cosine of the angle Θ between the arms and chains.

Isolating one shell of the bucket, (Figure 4) the forces acting upon it when closing are the following:

mn—the thrust of the two arms.
no—one-half the upward pull of the main shaft.
op—the horizontal pull of the opposite shell.
pq—one-half the weight of shaft and spool.
qr—the weight of the shell itself.
rm—the resistance offered by the bottom material to the cutting lips of the bucket.

Beginning at *m* and going clockwise, the force polygon is as shown, *mnopqr*. The force *no* represents one half the sum of the closing wire and closing chain tensions. The force *qr* acts through the center of gravity of the shell. For any given position of the bucket, the force *rm*, or the cutting resistance at the lips, will be maximum when the tension in the closing wire is greatest (i.e., when equal to the weight of the submerged bucket) but when this condition obtains, the bucket is on the verge of rising so that the vertical component of *rm* is zero, or, in other words, the cutting force *rm* at the lips becomes horizontal, and its value may be determined for any position of the bucket by taking moments about the main shaft as a center, after computing *mn* as above and approximating the weight *qr* and its point of application. The form of the shell, therefore, in so far as it influences the magnitude of the moments *mn*, *qr* and *rm* about the shaft, is an important factor, i.e., the shape of the inscribed triangle formed by lines joining the main shaft, arm-pin and edge of lip determines the relation between the lengths of the lever arms of the forces acting.

From the above considerations, the following conclusions may be drawn in reference to the bucket's ability to dig, or, in other words, its closing power as measured by the cutting force at the lips:

1. It is a function of three co-related quantities: the weight of the bucket, the form of the shell and the ratio of diameters of central sheave and chain spools.

2. It varies inversely with the depth of bucket from shaft to lip.

3. It varies directly with the width and weight of the bucket and with the diameter ratio of sheave to spools.

4. Weight in or near the curved back of the shells is no more effective than that concentrated about the shaft.

Bucket Axioms.—The bucket designed for soft-digging need not have inordinate closing power. It is made, therefore, as light as consistent with strength and durability and, in shaping the shells, the consideration of maximum capacity outweighs that of the adjustment of the inscribed triangle to maximum closing moment. The ratio of the diameter of the closing wire sheave to that of the closing chain spools is less than in the hard-digging bucket.

The hard-digging bucket requires great weight that it may obtain a full load in refractory material and, since the maximum combined weight of bucket and contents is fixed by the power of the main engine, bucket capacity must be sacrificed to bucket weight. A dredge capable of swinging a 10 yard soft-digging bucket will carry a somewhat smaller hard-digging bucket, probably about 7½ yards. The relatively large sheave to spool ratio, essential to the hard-digging bucket, results in a central sheave of considerable diameter, since the diameter of the closing chain spools cannot be less than enough to reel up with one revolution a sufficient length of chain to close the bucket. The designer should be mindful, however, that the perimeter of the sheaves must not extend below the horizontal plane through the lips of the open bucket, for the reason that, on a hard level bottom, the bucket so built instead of resting on its two lips in the wide open condition, would be supported by one lip and the central sheave and would have to close partially before being able to "bite." This fault is negatived in the soft-digging bucket by the nonresistance of the bottom. It is entirely possible, too, that the closing power be excessive in proportion to the weight, causing the bucket to close too quickly before attaining the penetration necessary to get a full load.

The depth of any bucket from main shaft to lips must not be so great with respect to the width that, when closed, the main shaft is so far above the horizontal plane through the arm-pins that the closing moment is materially reduced for the last part of the closing. A bucket having this fault may be difficult to keep closed when loaded and will open very quickly.

The curvature of the shells in front elevation should be sharper than a full quadrant so that the bucket will not fit the "bite" so neatly as to create a mud suction resisting the lifting of the bucket.

In side elevation, the lips of soft-digging buckets may be straight or nearly so without detriment, but in the hard-digging type, lips of considerable curvature are more effective.

All buckets should be so designed in regard to shell curvature and maximum spread of opening that, when wide open, all parts of the shells may lie within the verticals through the lips. Otherwise, the pressure of the water upon the protruding shell surface has a tendency partly to close the bucket.

The Sliding Cross-Head Bucket.—It is difficult to design a hard-digging bucket of the common type just described that will combine all the advantages and omit all the faults mentioned. Better results can be obtained in tough bottom by the use of what is known as the *sliding cross-head* type, Figure 1, page 5. It consists, in principle, of a common grab bucket supplemented by a rectangular frame, the two side members of which act as guides for the travel of the cross-head and the lower member of which is formed by the main shaft of the bucket. The shells, instead of hinging directly on the main shaft, are pin-connected to the lower corners of a pair of triangular links, which, in turn, are hung from the main shaft. Thus the hinge centers of the shells are below the main shaft, with a consequent decrease in the length of the lever arm of the force *rm*, Figure 4, resisting the closing of the bucket. All the desirable features of an efficient bucket may readily

be embodied without the presence of any of the faults. In addition to the prime advantage of great closing power, this bucket has the further good points that the elevation of the spool above the shell hinges allows plenty of open spread, keeps the spool clear of the contents of the loaded bucket and raises the central sheave well above the plane of the lips when open; while the frame adds effective weight, stiffens the entire structure and provides convenient fastening for the bucket poles. On the whole the sliding cross-head bucket is an excellent, durable and efficient tool.

For soft digging, however, the author prefers the common grab type, as, in this case, greater closing power is not required nor are bucket poles, and the frame, by adding unnecessary weight, reduces the capacity of the bucket.

Other Types.—In addition to the above, there are many types of grab buckets, some differing in minor detail and several in closing principle.

Many small buckets, *i.e.*, from about ¾ to 1½ yards capacity are rigged to close by a three and four sheave block purchase through which the closing wire is reaved. This type is seldom used in dredging however.

Buckets of larger size have been constructed with the arms pinned to lugs projecting from the back or convex side of the shells, outside the bucket, in order to yield greater closing moment by increasing the lever arm length of the arm thrust.

The *Stockton* bucket resembles, in principle, a huge pair of tongs, to the ends of the long curved handles of which, the bridled closing wire is attached.

The *Arnold* bucket is closed by compressed air, which drives a piston in a cylinder contained in the bucket. The object is to correct the omnipresent fault of the common grab consisting of the loss in effective closing weight due to the lifting propensities of the closing wire.

The *Williams* bucket, page 14, is a powerful, capable tool, unique in its closing power arm.

There are several single-wire buckets on the market,

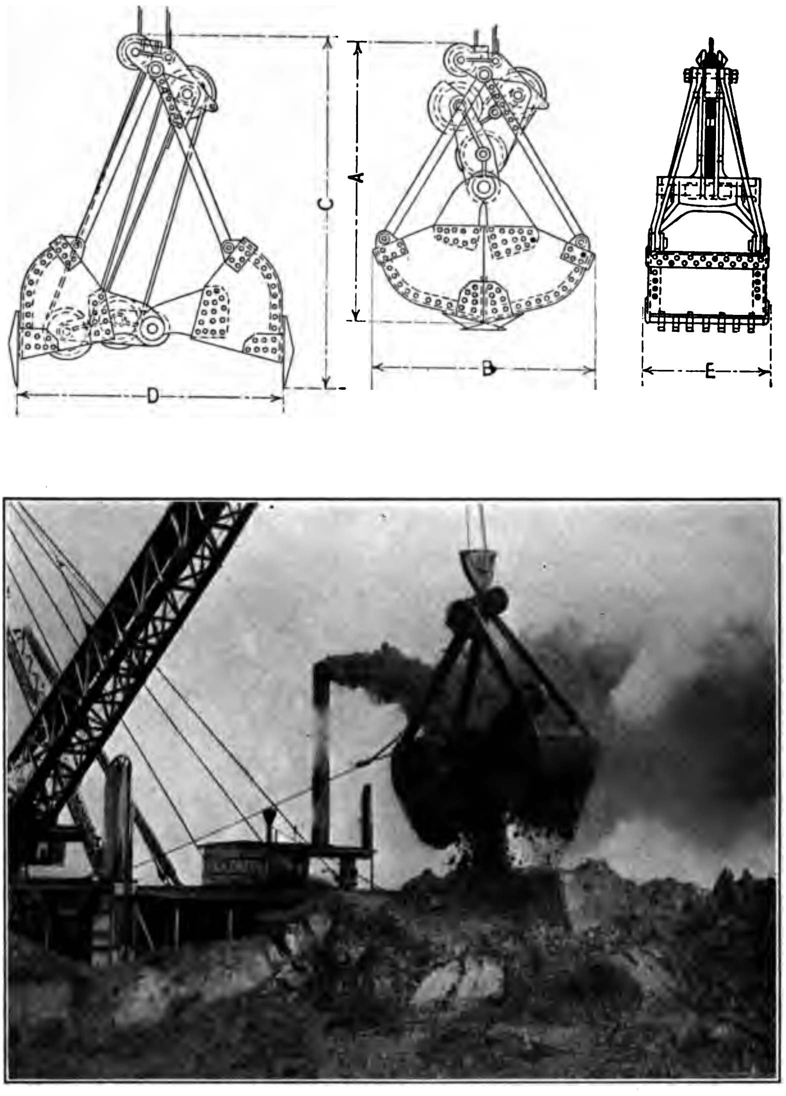


FIG. 5.—The Williams bucket. (*Courtesy of G. H. Williams Co.*)

but they are seldom used in dredging. They present the advantage of ready attachment to any two-drum hoist.

Grab Bucket Details and Appurtenances.—Both the cross-head and the shells may be either monolithic steel castings or built up. If castings, the shells, after wearing away at the cutting edge, may be fitted with attachable lips. The built up shell is made of steel plates varying in

FIG. 6.—Three blade orange-peel bucket in operation. (*Courtesy of the Hayward Co.*)

thickness from about $\frac{3}{8}$ to $\frac{5}{8}$ inches according to the size of the bucket. They are reinforced at the corners and edges with bent plates and steel castings and usually at one or two intermediate points in the width of the curved face with plates and angles. The cutting edge or lip of each shell is generally strengthened by the addition of a steel casting or, preferably, manganese steel, the better to resist the severe abrasion. The arms, in section are variously round, square,

rectangular and "H" shaped. All parts of a bucket, more particularly the pins, shafts and pin and shaft bearings should be generously proportioned and provided with renewable bushings.

The capacity of a bucket may be increased temporarily for soft digging, *i.e.*, in material that has sufficient body and cohesion to stand up, by the use of so-called "side-boards" which are bent plates bolted to the arms, one to each shell, and having the effect of raising the backs and sides of the shells.

The tendency of the bucket to rotation must be prevented, as otherwise the two bucket wires would become crossed and fouled. This is accomplished in one of two ways. A wire called a "dorsey wire" is attached to the side of one of the bucket shells and is lead by sheaves up through the boom, about midway of its length, to a small pendant weight, rising and falling in the plane of the gallows frame. Or a pair of hardwood poles may be fastened to or set in the uprights of the bucket frame, extending up through rings attached to the boom head. The poles have the additional function of maintaining the bucket in an upright position on the bottom, *i.e.*, preventing it from "falling over" when landed upon sloping, hard material. For this reason, they are considered by many "mud-diggers" to be an absolute necessity for efficient dredging in hard stuff.

Teeth are rarely used on large buckets, but on the smaller types, which are relatively light in weight, they are often helpful.

Boom, "A" Frame and Back Guys.—The derrick or crane element of the dredge, by which the bucket is handled, comprises boom, "A" frame and back legs with guys. The "A" Frame is usually vertical, or nearly so, and is set some distance back from the bow of the hull in order better to trim the ship and to permit a sufficient length of hull forward of the boom heel for holding the scow alongside when the first pocket is being loaded. Back guys and usually also back legs, *i.e.*, struts paralleling and supporting

the tension rods, extend from the peak of the "A" frame down to the after deck. There are generally two such. The boom heel is approximately in the plane of the "A" frame and its upper end is suspended from the peak of the "A" frame by a topping fall of fixed length so that the boom

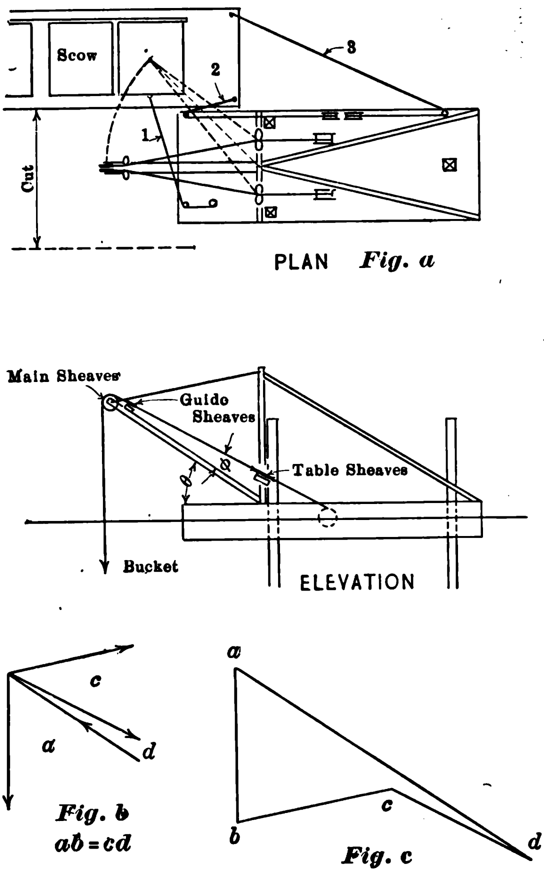


FIG. 7.—The grapple dredge: (a) arrangement; (b) boom-end forces; (c) boom end force polygon.

has a constant angle of inclination, which, for loading scows will be from 35 to 45 degrees with the horizontal, and generally less than 35 degrees for long-boom, banking machines. The two bucket wires pass over main and guide sheaves at the boom end, thence between the so-called "Table

sheaves" mounted on the "table" which is analagous to the horizontal bar of the letter "A" in the "A" frame, and from there to the drums of the main engine. The two sets of table sheaves are spread some distance apart athwartships for the purpose of giving the bucket wires enough lead to the boom to swing it.

The weight of the loaded bucket and the boom and the pull of the engine create stresses in the boom, topping fall, "A" frame and back guys, which are readily determined. The manner of rigging and the forces acting at the boom end are shown in Figure 7a and b, and the stress diagram in Figure 7c. For the analysis, it will be assumed that the closing wire lies in the same vertical plane with the boom and that it takes the entire load of bucket and contents. Since this wire passes over a sheave in the boom head, the forces *ab* and *cd* representing the tension in it must be equal to each other and to the weight in air of the loaded bucket. It is advisable to increase all stresses by an impact allowance of at least 50 per cent. The boom compression *ad* and the topping fall tension *bc* may be scaled from the diagram, a study of which will reveal that both these stresses increase with the decrease in the boom angle θ and also with the decrease in the angle ϕ between boom and closing wire to engine.

To the above stresses must be added those due to the weight of the boom, which may be found graphically by drawing a second force polygon of the three forces, end reaction of weight of boom, boom compression and topping fall tension, omitting the bucket and closing wire.

The topping fall tension creates stresses in the legs of the "A" frame, alternately tension and compression as the boom swings and maximum when the boom is at the limit of its arc. The tension in a back leg will be greatest when the boom is in the plane of that leg. A graphical analysis will easily yield these stresses.

The boom is designed for combined compression and bending due to its own weight. The choice of section is influenced by the use of wire cable or chain for the bucket

operation. Either may be employed with equal success, the preference being largely personal. If wire is used, the sheaves in the boom and on the table must be of large diameter in order to prevent undue bending stresses in the cable. The end of the boom, therefore, must be designed in such a manner as to provide a fork between the prongs of which, the two large sheaves are mounted on a shaft. The guide sheaves need not be so large. If chain is selected, all sheaves can be much smaller and those at the boom head may be suspended beneath the boom. There are many types of boom. In the smaller machines, it may consist simply of a single stick of timber with or without truss rods. In the larger dredges it may be built up of two timbers braced together side by side with sufficient clearance between to contain the two end sheaves. The timbers are often reinforced with steel plates or channels. Or it may be a lattice or truss boom of timber or of steel. A convenient form of the latter comprises four angles laced both ways and with deep plates at the ends and one intermediate point at least. Booms of this type require transverse or sway frames to resist racking strains.

The "A" frame members, if built of wood, must be supplemented with steel stay rods because of the reversal of stress. Although the back legs are subject to compression only in rare instances, yet it is advisable to combine in them both strut and rod the better to hold the "A" frame rigidly and truly in its intended plane without oscillation or vibration.

All sheaves, shafts, boxes and the derrick fittings should be proportioned generously to withstand the exceptionally severe wear and tear and to cut repairs and renewals to a minimum. The connections of the "A" frame and the back legs to the hull and the bearing and thrust of the boom heel casting upon the hull require care as to the proper transmission of the stresses to the hull and will influence the hull design to the extent of the provision of adequate strength at those points.

Spuds, Spud Wells and Gallows-Frame.—The grapple dredge is held in position, oriented and advanced in cut by means of spuds alone, or by wires alone, or by a combination of spuds and wires. Many machines are fully equipped both with a full complement of spuds and spud handling apparatus and with all the necessary machinery and appliances for operation by wires and anchors. This dual arrangement is obviously advantageous, since, while the spud method is more convenient through the saving of lost time in running lines and anchors and through the

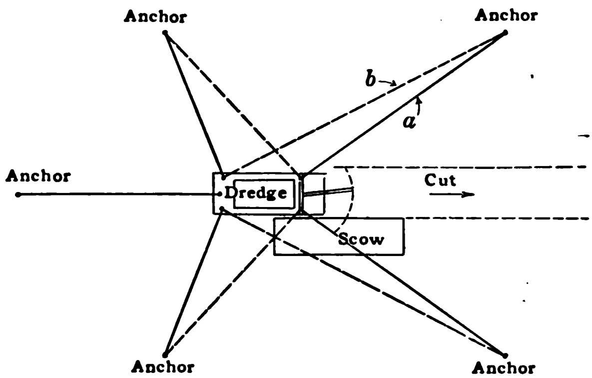


FIG. 8.—Grapple dredge. Position control by wires.

non-interference with traffic and adjacent structures, yet there are times when the wires must be used, as in deep water or in swift currents or in the event of the breaking of a spud.

For position control by wires, five lines are generally used, two quarter lines on each side and a stern wire. They may be arranged as in Fig. 8a, or as in Fig. 8b. The rigging of 8b presents advantages over the former in that the two quarter lines forward are not as likely to foul the bucket in digging and dumping into the scow. In either case, the two wires on the scow side of the dredge, usually the starboard, must be elevated to clear the light scow. This is done by leading them from the drums up through overhead sheaves, one attached to the end of a cross arm set in the

"A" frame or gallows-frame for the bow wire and another mounted on a post or column erected on the after deck for the stern quarter line. Some machines have symmetrical wire equipment so that the wires may be elevated on either or both sides. Others have but two spuds, used in connection with the wires. It is readily seen that the high wires on one side and the low deck wires on the other exert a force couple tending to resist the listing of the dredge in the direction of the low wires when the boom is swung to that side.

Another expedient, which has been successfully used, to prevent scow and other interference with the anchor wires is the complete submergence of the wires by running them through sheaves in the toes of the spuds. This arrangement has been patented by the Osgood Dredge Company. The 10 yard clam-shell dredge "Finn Mac Cool" was so equipped.

The spuds in the smaller dredges are single sticks of round or square timber. In the larger machines they are square built-up members comprising four or nine pieces of heavy square timber bolted together. Some spuds are as large as four feet square. They are equipped with pointed metal shoes to facilitate penetration into the bottom and to add enough weight to overcome the buoyancy of the timber. All-steel and wrought iron spuds are sometimes used, both round and square.

The spud wells or openings at the deck through which the spuds travel may be either holes in the hull or housings attached to the sides and stern of the hull and called "outside" wells. The spuds must have sufficient clearance in the wells to permit perfect freedom of operation.

Three spuds are required for control entirely independent of wires, two forward at the sides and one aft, in the center. The two forward spuds are suspended from a tall, vertical rectangular frame called the "gallows-frame" approximately in the plane of the "A" frame and often braced to it. The stern spud is hung from a frame of more humble proportions or from a single mast maintained plumb

by guys. The gallows-frame consists simply of two or four columns with a top cross cap and the necessary transverse struts and diagonal braces or knees. It must be borne in mind that the load upon the gallows-frame may be much more than that due to the dead weight of the spud because of the difficulty frequently encountered in pulling the spud out of the tenacious river bottom, i. e., "breaking the suction." It even may be greater than that developed by the maximum pull of which the spud hoisting engine is capable due to the fact that the careening of the dredge when digging is resisted by the reaction of the spud on the high side, comprising both weight of spud and the grip of the mud. The spuds are raised by the spud engine, having a wire leading through a sheave at the gallows-frame cap thence down to a collar encircling the spud and free thereof, but which grips the spud when the wire is taut. In rarer instances, the spud wire is made fast to the spud well housing from which it is lead down through a sheave in the toe of the spud itself, thence up through the gallows frame sheave and finally to the drum of the engine. Rigged so, the gallows frame need not be as high as the full length of the spud.

It is interesting to note here that in the case of a dredge swinging a long boom, excessive listing is sometimes prevented by the use of boom logs attached to the sides of the hull by chains of such length that the logs are afloat when the machine is on an even keel, but are raised clear of the water when the boom swings to the opposite side.

The Machinery.—The usual machinery of the clam shell dredge comprises the following units:—

1. *The Boiler:* The Scotch Marine is a general favorite although Locomotive, Leg, Vertical and others are used. It is usually designed to carry from 125 to 150 pounds pressure, and is located aft, where, with the appurtenant coal bunkers and water tanks it acts as a counterweight to the active loads forward.

2. *The main engine for operating the bucket wires:* generally a two cylinder horizontal type driving two drums

through pinions, spur gears and frictions. The drums are in line athwartship and spread to give a direct lead to the table sheaves. The frictions may be either of the block or disc type, the latter being preferable for large machines. The pinions are as a rule below the elevation of the drum shaft. In the older dredges, the drums were thrown into clutch with the frictions by means of a long hand-operated lever in the pilot house. Now, however, steam or compressed air is used, except in small machines. The frictions are a very important item of the unit and should be given careful consideration. For efficient digging their grip must be positive and their release quick and complete.

3. *The Secondary Engines:* The operation of the spud hoists, the anchor wire drums and the capstans or drums (as the case may be) for scow lines may be accomplished through two engines if desired, one forward and one aft. If the dredge be fully equipped with a complete complement of spuds and anchor wires and with symmetrical scow-handling equipment for right and left hand digging, a total of 14 drums or drums and capstans are required, 3 for the spuds, 5 for the anchor lines, and 3 on each side for scow control. The secondary engines should be double cylinder.

4. *Pumps:* A minimum of two pumps is essential, one for the boiler feed and the other for pumping from the bilge, water tank or water scow and for fire purposes. If a surface condenser be used, circulating and air pumps will be required.

5. *Condenser:* The main and secondary engines may be run as condensing engines by piping the exhaust steam from all to a single condenser.

6. *Miscellaneous equipment,* such as electric light plant, air compressor and refrigeration plant.

The runner's control in the pilot house comprises simply main engine throttle and frictions. The secondary engines are under local control upon signal from the pilot house.

An idea of the relative engine sizes may be had from the following data: The dredge "ADMIRAL," shown on

the frontispiece, has a hull 110 ft. × 39 ft. × 11 ft. 10 in., swings a 7½ yd. bucket and has a horizontal, two-cylinder main engine 20 in. × 24 in. The dredge "BALTIC," American Dredging Company, has a hull 110 ft. × 39 ft. × 12 ft., a 5½ yd. bucket and a horizontal two-cylinder main engine 16 in. × 24 in. The dredge "COLUMBIA," of the same Company, has a hull 90 ft. × 35 ft. × 10 ft., a 4 yd. bucket and a two-cylinder horizontal engine 14 in. × 20 in. The "PACIFIC" (same owners); hull 78 ft. × 23 ft. 9 in. × 7 ft., bucket 2¼ yd., main engine, two-cylinder, horizontal 10 in. × 15 in. The dredge "FINN MAC COOL;" hull 120 ft. × 40 ft. × 12 ft. 6 in., bucket 10 yd. (soft digging) main engine, two-cylinder, 18 in. × 24 in. The "ADMIRAL" mentioned above will swing a 10 yd. soft-digging bucket. Dredges of this size usually have secondary engines of from 8 × 10 to 10 × 12 double cylinder. The engines of clam shell machines are seldom run condensing.

The House.—The usual grapple boasts a two-story frame or steel house, the first floor of which comprises boiler and engine housing, galley and mess room; and the second floor, pilot house or operators room, and sleeping quarters for the crew and inspector. Deviations in detail from this arrangement are not uncommon. The main engine and boilers are generally depressed below the main deck.

The Hull.—The dredge hull must be of sufficient size to contain, with comfortable freeboard, all the above mentioned superstructures and machinery with adequate fuel and water storage. The beam and the length forward and aft of the "A" frame must be sufficient to provide adequate stability when dredging, i. e., to keep the ship in reasonable trim in resistance to the listing moments of the swinging boom and bucket. The width of hull cannot be so great, on the other hand, as to necessitate an excessive length of boom in order to reach beyond and clear the pocket coaming of the light scow. The freeboard should be such as to assure some reserve buoyancy when the machine is at the point of maximum inclination due to the limiting position

of the loaded bucket in its arc. In brief, the problem is the proper co-ordination of hull dimensions with the location and height of "A" frame, length of boom, bucket capacity and disposition of machinery, fuel and water tanks. The solution is simplified by the commonly rectangular shape of the hull both in plan and section, with rake at the stern only to facilitate towing. Moulded hulls have been constructed for grapples but are quite rare. The total depth of hull is the sum of the draught of the empty hull, the displacement depth due to machinery, superstructures, fuel and water, and the desired freeboard. The first quantity is first approximated by roughly estimating the total feet board measure of lumber in the hull (or the tonnage, if steel) and checked subsequently from the accurate bill of material taken from the detailed design. The ratio of hull depth to the width is as a rule slightly less than 1 to 3 and that of beam to length a little more than 1 to 3.

The principal loads acting upon a dredge hull are the normal water pressure on bottom sides and ends; the weight of the machinery, more or less concentrated under the main engine and boilers; the pull of the main and secondary engines; the weight of fuel, water tanks and superstructure; the thrust of the heel of the boom which may be in any vertical plane passing radially through the heel casting; the alternate thrust and pull of the A frame; the pull of the back guys; the bearing of the gallows-frames; horizontal force couples due to spuds in their wells or to anchor wires; and finally wave action, causing both local impact and bending moments in the structure as a whole. While the majority of the above loads are capable of reasonably accurate determination, it is hazardous to design upon a purely theoretical basis. The efficiency of a dredge depends among other things upon the ratio of its working time to the total. The more the time lost for repairs and renewals, the less valuable is the unit. Therefore, either temper the theory with the knowledge resulting from practical experience or else use a large safety factor, to the end

that the members shall be proportioned generously to withstand the severe duty required of "mud-diggers."

Most hulls are built of wood. They are virtually heavily constructed boxes stiffened with bulkheads, trusses and knees to resist distortion. A hull that has become convex upward longitudinally is said to be "hogged" and when concave upward, "dished." Although varying widely in detail, the usual design is, in principle, as follows: The bottom planking is laid transversely upon the under side of longitudinal keelsons, heavy timbers spaced from about 2 ft. 6 in. to 4 ft. c.c., extending the full length of the ship and spliced with long scarf joints from 4 to 6 ft. in length. The reactions of the keelsons are taken by heavy cross keelsons, running athwartship at greater intervals on top of the keelsons and notched down and over them. Upon the cross keelsons in turn bear the longitudinal bulkheads or trusses and the stanchions. There are at least two trusses, usually of the Howe type, or solid bulkheads extending the full length of the hull which, with the keelsons and side planking (acting also as deep longitudinal girders) furnish the requisite stiffness fore and aft. Upon the trusses, bulkheads and stanchions are placed the deck beams carrying the deck planking. More commonly the deck beams are transverse members and the decking longitudinal. The deck is usually crowned about 3 inches. The side planks, called "strakes," are spiked to the side stanchions, the thrust of which is transmitted to the cross keelsons and the deck beams by fore and aft ribbon pieces sometimes called side cleats. Frequently two or more side strakes are thicker than the others, extending beyond the side plane and acting as fenders. The inclined members of the stern are called rake timbers. All the exposed planking is dressed, outgaged and caulked with pitch and oakum. Deck spikes are covered with wood plugs. Transverse stiffness is provided by lateral bracing or by hackmatack knees.

Operation.—The dredge is towed to the site of the work and placed in position at the starting point of the project.

Her spuds are dropped or lines and anchors set as the case may be. The cut to be dredged is indicated by range targets stationed ahead of the dredge. A light scow is brought alongside by the tug acting as tender and moored to the machine by the wires of the scow handling machinery, which are generally 3 in number located as follows: A breast wire leading from a "U" bolt in the pocket coaming of the scow to the port bow of the dredge; a second wire attached to the port stern corner of the scow and running forward to the starboard bow of the machine; and a third wire extending from the starboard stern of the scow to the starboard stern of the dredge. The arrangement is shown in Figure 7, page 17. It is customary to interpose a boom log between dredge and scow.

The deck hands board the scow and, using bars as levers, wind up the door chains of each pocket about the shaft until the doors are raised to the closed position and held so by ratchet and pawl. The end pocket nearest the dredge having been thus closed, digging is started.

The operator in the pilot house releases the starboard friction to slack the closing wire and the bucket opens hanging by the port wire. He then slowly lowers the open bucket into the water by easing up the port friction until the bucket rests on the bottom, ready for the bite. He releases the port friction, grips with the starboard and partly opens the throttle. The closing wire is thus stressed and the bucket closes upon its load and rises. Keeping the load on the closing wire and controlling the resulting boom swing to starboard by a lesser backing strain on the port wire, the operator lifts the bucket up over the side of the scow and pocket coaming until it is suspended above the pocket, when he closes the throttle, holds fast the port wire and releases the starboard, opening the bucket. Still gripping with his port friction, he opens the throttle partially, swinging the boom to port and then lowers it open into the water as before to take another bite. When the pocket is fully loaded, he signals by blowing the whistle to the deck hands who haul the scow aft by operating the

scow-line drums until the next pocket is in position for loading. The scow settles more and more deeply in the water as the loading progresses, constantly decreasing the necessary height of bucket lift.

If dredging in tide-water, the operator must know the stage of the tide so that he may dig the depth specified, referred to the datum, usually mean low water. A tide guage, therefore, is set where he can see and read it. In addition to actul lead-line soundings over the bow of the dredge, he is guided in his digging by his knowledge of the overall height of the bucket or by graduations, or a single mark upon one of the bucket wires or chains or upon the bucket poles, or by means of a wire leading from the bucket through sheaves in the boom end and "A" frame thence through reduction tackle to a weight sliding on a graduated scale in the pilot house.

When specified depth has been made over the area within reach of the bucket, the dredge is moved ahead or "advanced in the cut." If the machine is operating under wire control, this movement is accomplished simply by winding in the forward quarter lines and slacking the stern quarters and stern line. If spuds alone are being used for position control, the advance is achieved by so-called "walking on the spuds," as follows: The bucket is grounded, i. e., lowered into the mud and the stern and one bow spud are raised clear of the bottom. The operator then stresses that bucket wire which tends to swing the boom toward the side on which the bow spud is up, but the boom is anchored by the grounded bucket and the dredge is free to pivot about the third spud, so that the boom retains its position and the dredge swings. When the free bow corner has thus been pulled forward the desired distance, that spud is dropped and the operation repeated for the advance of the other bow spud, after which the stern spud is dropped and digging is resumed. When all pockets of the scow are full, the operator blows for the tug to bring a light scow and to remove the loaded one.

CHAPTER III

DIPPER DREDGES

General Description.—As has been said, the Dipper Dredge "digs" like the familiar steam shovel. The bucket, which is essentially a scoop with heavy teeth and a flap bottom, is attached to the end of the dipper stick, which is carried by the boom at or near the centre of the latter. The boom is supported by "A" frame and back guys as in the grapple, except that, frequently, the "A" frame is tilted forward, when it is termed the "shear legs." The boom is necessarily of heavier construction than that of the grapple and, with the "A" frame, is set well forward at the very bow of the hull.

The bucket obtains its load by digging into the bottom under the impetus of dipper stick and bucket wire, which runs over a sheave in the boom head and thence to the main engine. The boom is swing in one of two ways; either as in the grapple by means of two bucket wires, or by bull wheel and swinging engine, the latter being the more common. The hull is stiffer and the spuds heavier than those of the grapple, because of the greater strains. The dredge is held in position by three spuds, and advances by grounding her dipper and stressing the backing chain. As a rule, the crew is quartered on the dredge. The scows are handled as on grapples.

The Bucket.—The bucket is an open steel cylinder, provided with a hinged flap bottom, a handle or bail and a reinforced cutting edge or lip, to which teeth are attached. Fig. 9 is a picture of a Bucyrus Dipper Dredge, swinging a 6 cubic yard bucket.

The bucket hoisting wire is made fast to the centre of the bail, and the backing chain, which draws bucket and dipper stick back toward the hull, is fastened either to the

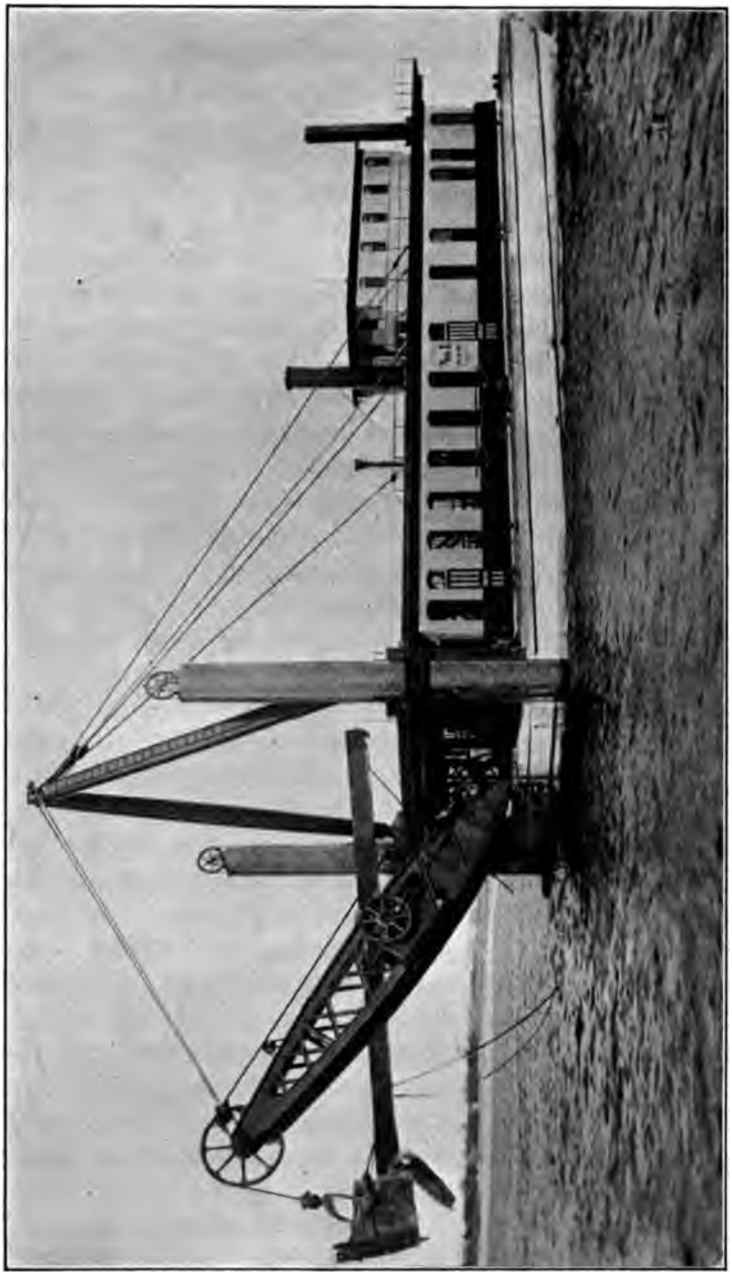


FIG. 9.—Six yard Bucyrus dipper dredge owned by Daly & Hannan—equipped with 16″ × 18″ main engines. (*Courtesy of the Bucyrus Co.*)

rear face of the bucket or to the dipper stick near the bucket. The bottom door or floor of the bucket is held closed by a latch, which locks automatically by virtue of its bevelled end when the door is forced upward and closed by the water pressure. The latch is drawn back to open the door by means of a line extending from it to a lever at a point near the fulcrum, and a second line from the end of the lever to the cranesman stationed at the heel of the boom. In the larger buckets the latch rests on roller bearings to facilitate its movement and, in the recent, large capacity, high powered machines, is steam operated. The teeth are usually from three to five in number, with tool steel points, and are detachable for sharpening and renewing.

Boom, Dipper Stick, "A" Frame and Back Guys.—The boom, as in the grapple, is hung from the "A" frame by a fixed topping fall, but is usually at a flatter angle with the horizontal than that of the grapple. The "A" frame, when vertical, is approximately in the plane of the heel of the boom, but, when inclined, the point of bearing on the deck may be some distance aft of the boom heel. For the same topping-fall stress, the stresses in "A" frame and back guys are greater in the case of the inclined shear legs than in that of the vertical "A" frame. The boom, necessarily, is set well forward in order that the dipper stick may clear the bow in all positions. The back stays, more particularly in those dredges having inclined "A" frames or shear legs, are frequently tension members only, without back legs or struts. There is a structural economy in the vertical "A" frame, in that it and the gallows frame may be designed as a unit frame, whereas the inclined "A" frame necessitates a distinct and independent gallows frame.

The boom is the most difficult part of the dredge to design. Some of the very heavy loads to which it is subjected are indeterminate, principally those caused by starting to swing the boom before the bucket is clear of the water, or even while still in the mud, and by sudden stoppage and reversal of swing. The principal boom stresses

are again combined compression and bending, but, in this instance, the bending is due to live as well as dead load and is very much greater. In addition there is, in those booms swung by a bull wheel at the heel, a horizontal bending movement, caused by the rotation of the bull wheel

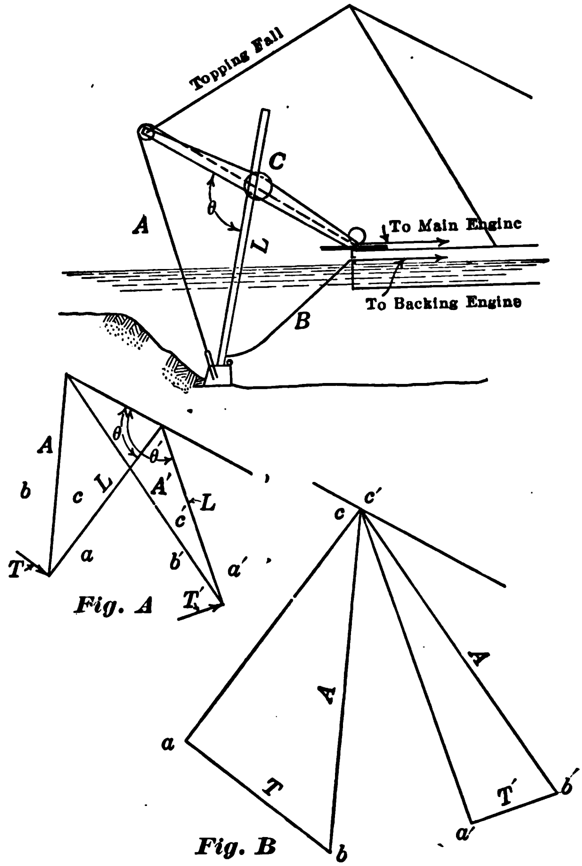


FIG. 10.—*A*, Forces acting at the dipper for two positions of the arm. *B*, stress diagrams for the two positions.

and maximum at the boom heel casting. Furthermore, the side thrust of the dipper stick requires considerable lateral boom stiffness. To investigate understandingly the vertical bending stress in the boom, a knowledge of the action and control of the dipper stick is necessary.

The stick has two movements, one of translation with respect to and through the boom at or near its mid point, and the other of rotation in a vertical plane through an arc centred at the same point. Referring to Fig. 10, the dipper may be pulled either toward the end of the boom by the main engine wire A, or back toward the hull by the backing chain B. The motion of the stick through the boom is controlled by two band friction wheels C on the boom, keyed to a shaft carrying a pinion which meshes into a rack on the under side of the dipper stick, so that the stick may be held fast at the boom at any point of its length, at the same time being free to rotate about that point. The stick is pulled up through the boom by the tension in hoisting wire or backing chain, or both, and drops down through the boom by gravity alone. Many dippers, however, are equipped with a so-called "crowding engine," which is mounted on the boom and *drives* the pinion meshing with the rack of the stick, so that the stick can be *pushed* or *pulled* through the boom. By this means, the dipper can be thrust out beyond the end of the boom to an increased reach.

It is apparent from the stress diagrams (fig. 10-b) that the digging power, or the thrust at the bucket perpendicular to the dipper stick, varies inversely as the length L of stick below the boom and the angle θ between boom and stick; and that the compression in the dipper stick is maximum when L and θ are maximum. This, then, is the critical loading of the stick and, knowing the greatest pull of which the main engine is capable, the maximum comprssive stress in the stick follows. Its length will usually be such as to necessitate the use of long column formula in its design.

It is entirely possible, too, that the dipper stick be subjected to tension, which, although insufficient to influence the choice of section, is enough to require a test of the stick details for resistance to the tensile stress involved, which will be the weight of the loaded bucket in air. This condition obtains when, through faulty operation, or the parting

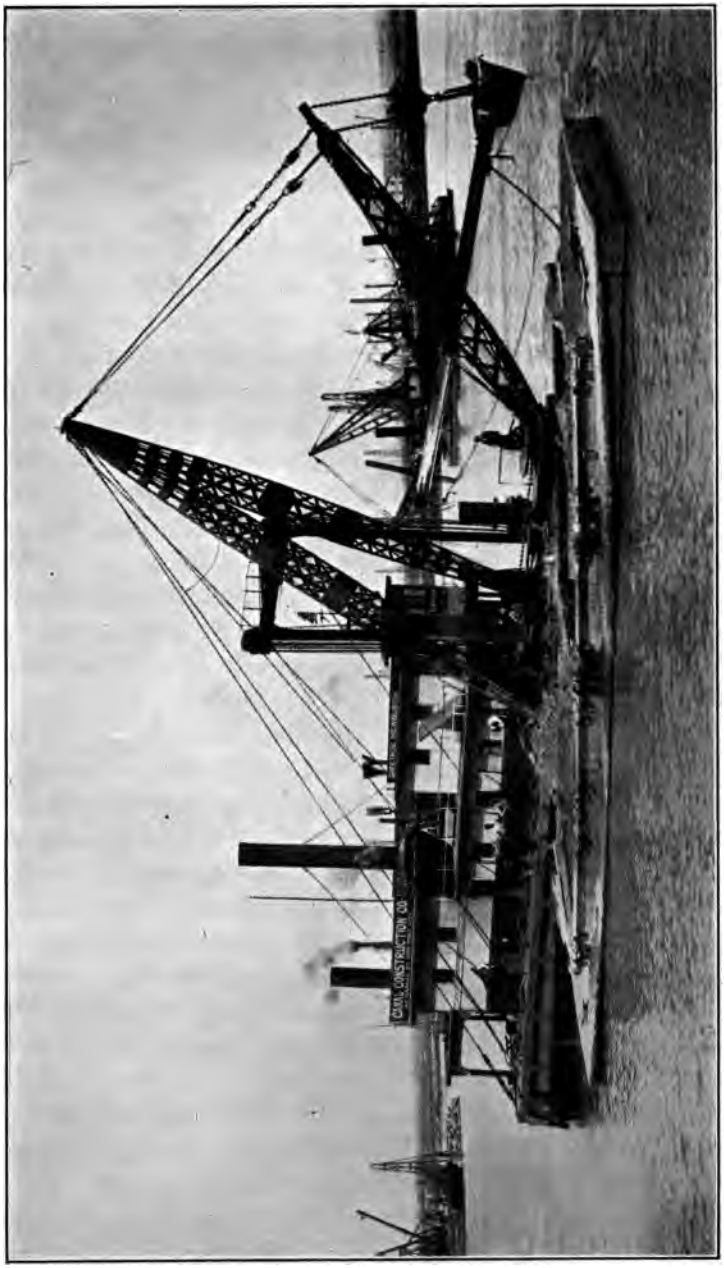


Fig. 11.—The Newburgh, Canal Construction Co., New York.

of the main hoisting wire, or slipping main engine frictions, the full load of the bucket and contents is suspended from the boom by the dipper stick, held by its frictions at the boom. If there be a crowding engine, the same tension may easily exist through the agency of that engine. In addition, there is a certain amount of twisting to be resisted.

The direct stress in boom and topping fall may be found graphically as in fig. 12. The forces *bc* and *ac,* fig. 12–B, representing the bucket wire tension, are obviously equal in amount, as are *ac* and *de* of fig. 12–C, because the wire passes over a sheave in the boom head, and are measured by the pull of the main engine. The boom compression is maximum when *ac* is perpendicular to *cd,* and the topping fall tension *cd* increases with the angle θ. It must be remembered in the design of the latter, that the angle θ is not limited by the vertical position of the bucket wire, as the bucket may easily be thrust out beyond the end of the boom, more especially by the use of a crowding engine. The dead load stress in the topping fall is obtained as described under grapples.

There are four values of bending moment to be considered in the boom: *a,* the positive vertical B.M. caused by the suspension of the loaded bucket and dipper stick as mentioned above; *b,* the negative vertical B.M., caused by the thrust of the dipper stick when perpendicular to the boom; *c,* the positive dead B.M. due to the weight of the boom itself; and *d* the horizontal B.M. as a result of the bull-wheel rotation. The critical condition of stress in the boom, then, is the greatest possible combination of direct compression and compressive fibre stress due to vertical and horizontal bending moment, not omitting to investigate and provide for the fibre tension. These stresses, in conjunction with those due to the indeterminate loads previously referred to and with the physical considerations influencing the shape and location of some of the members, result in a sort of compromise design. *a* and *b* are maximum at the point of intersection of dipper

stock and boom; *c* at the centre of the boom; and *d* at the heel casting. The horizontal B.M. *d* is equal to the pull of the swinging engine multiplied by the radius of the bull wheel. It has little bearing upon the choice of the boom

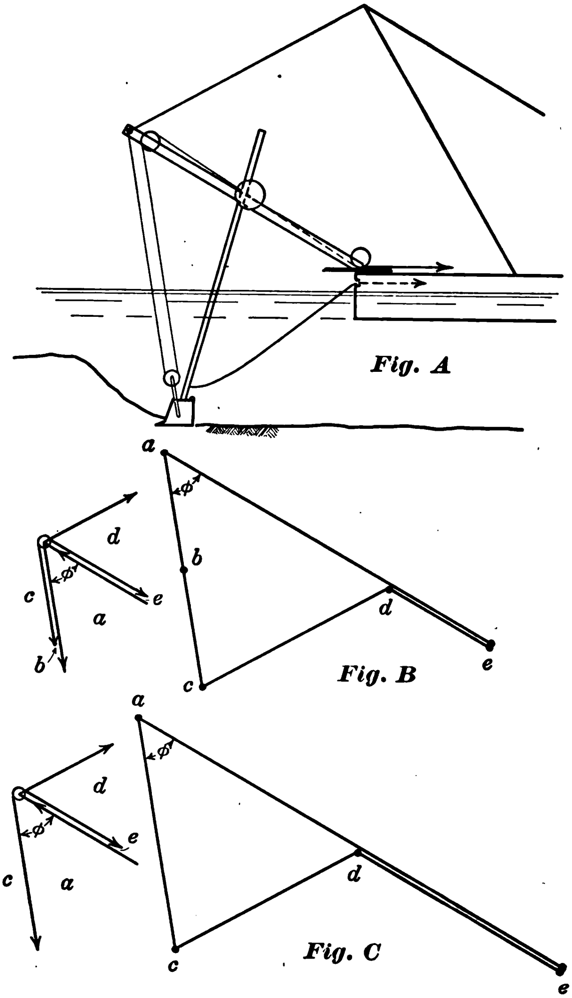


FIG. 12.—*A*, The purchase-rigged dipper. *B*, boom-end forces and stress diagram for purchase-rigged dipper. *C*, the same for the direct-wire dipper.

section, but is an important destructive agent acting upon the heel casting and the boom structure immediately adjacent thereto, and one warranting complete investigation and the provision of ample resistance.

Some dippers are rigged with a single sheave purchase in the bucket wire, fig. 12–A; i.e. the end of the wire is attached to the boom end, from whence it passes down to a single-sheave block fastened to the bail of the bucket, thence up over the boom-head sheave and to the main engine. It is apparent that the result of such a rigging is to double the lifting power of the engine and to halve the lifting speed and that, in dippers of the same digging power, the boom stress in the machine which is purchase rigged will be less than that in the direct wire dredge (Fig. 10).

The boom is a relatively large member, having considerable depth at the dipper stick and tapering toward both ends, and is of plate, girder or latticed truss construction.

The stress in "A" frame or shear legs and back legs or stays are found as for grapples in Chapter I.

Spuds.—The two bow spuds are set either in "outside" or "through" wells. They are of heavy section and are subject to considerable bending moment occasioned by the reaction of the forward thrust of the dipper. Some dippers are rigged to "pin up," a term applied to the process of maintaining the dredge upon an even keel while digging, by transferring part of the weight of the machine to the two bow spuds, so that it is not dependent upon the stability of the hull to resist transverse oscillation. In pin-up dredges, the fore spuds are provided with sheaves both top and bottom. A wire attached to the spud-well housing, running down around the toe sheave and thence up to the drum of the spud hoist, raises the spud, and a second wire of larger diameter, fastened at the same place and leading up over the top sheave and down to the drum, becomes taut when the dredge attempts to list to that side, tending to force the spud more deeply into the bottom.

The dredge advances by grounding her bucket well ahead of the bow, raising the two bow spuds clear of the bottom and stressing the backing chain, which pulls the machine toward the dipper. The stern spud remains in the mud during the operation, and, having a slotted well, slowly inclines forward as the dredge progresses. It is

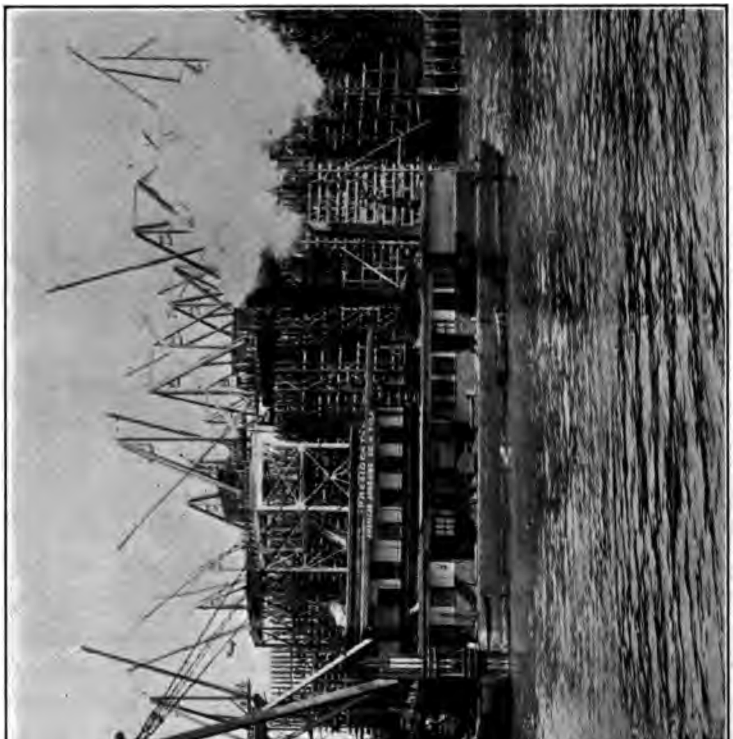


FIG. 13.—The President—American Dredging Co., Phila., Pa.

called the "walking-spud" or "trailing-spud" on this account. The spuds are raised by spud hoist and gallows frame, or by a rack on the spud engaging a pinion at the deck level, obviating the necessity of a gallows frame.

The Machinery.—In dipper dredges having two bucket wires to swing the boom and raise the bucket, the main engine is a two cylinder horizontal type, with two drums

FIG. 14.—Dipper dredge with bank spuds. *(Courtesy the Marion Steam Shovel Co.)*

as in the grapple. If the boom is controlled by swinging engine and bull wheel, the main engine may have but one hoisting drum. In some machines, the drum cylinder is of large diameter for part of the width, stepping down to a smaller diameter for the balance, the object being to increase the pull on the bucket wire during the early stage of digging when the bucket is loading, after which the wire coils upon the larger drum surface, accelerating the raising of the dipper. Such a device is termed a differential drum, and is used to good advantage with the purchase rigged

dipper. In addition to the main and swinging engines, complete dipper control requires an engine for handling the backing chain which draws the bucket back toward the hull. Some machines are equipped also with a crowding engine mounted upon the boom, with the function of dipper stick motion as previously described. The machinery for spud and scow handling is similar to that of the grapple.

FIG. 15.—The Tellico—U. S. Army Engineers—1½ yd. dipper, triple hitch. (*Courtesy the Osgood Co.*)

The dredge PRESIDENT, American Dredging Company, pictured on page 38, is a "pin-up" machine, with direct wire rigging, bull wheel and crowding engine, hull 105 ft. × 39 ft. 8 in. × 10 ft. 7 in., 2 cyl. hor. main engine 14 × 16, and a 4½ yd. dipper.

The Hull.—In general dimensions and construction details, the hull is very similar to that of the grapple. There is, however, a need for greater stiffness due to the thrust of the dipper and the extreme forward mounting of the boom. In some types, e.g., the Bucyrus built machines, the longitudinal trusses are steel and of great

depth, reaching from the cross keelsons to the roof of the deck house, and tied horizontally by a top lateral truss. There is, too, relatively less stability forward than in grapples to resist listing when the bucket is swung out over the scow, from which it is apparent that the same hull will carry a grab bucket of larger capacity than a dipper.

The bow structure of the hull must be well stiffened and the truss and superstructure design there is dependent in some measure upon the locating of the bull wheel, which may be upon the deck or elevated to the plane of the roof

FIG. 16.—14″ × 16″ engines and hoisting machinery for a 6 yd. dipper dredge. (*Courtesy the Bucyrus Co.*)

of the deck house. In the latter position, it exerts a more direct pull upon the boom, thereby reducing the lateral stresses in that member.

Operation.—Dippers require two men to operate the boom, dipper stick and bucket, in addition to the usual crew of engineer, firemen, oilers and deck hands. One, the "operator" or "runner," controls the bucket hoist, backing chain and boom motion through the throttles and frictions of the main, backing and swinging engines. The other, the "cranesman" or "dipper tender," is stationed at the boom heel and regulates the dipper stick frictions on the boom and opens the bucket.

In the process of digging, the runner slacks the bucket wire or wires, permitting it to drop into the water, at the

same time pulling it back toward the hull by stressing the backing chain. The cranesman releases the dipper stick frictions so that it falls through the boom until the dipper rests on the bottom. The runner releases the backing chain and stresses the hoisting wire, and the dipper tender applies his friction bands, gripping the dipper stick at the boom. The bucket, therefore, cuts its way forward in an arc of radius equal to that portion of the dipper stick below the boom until it is loaded and clear of the mud, whereupon

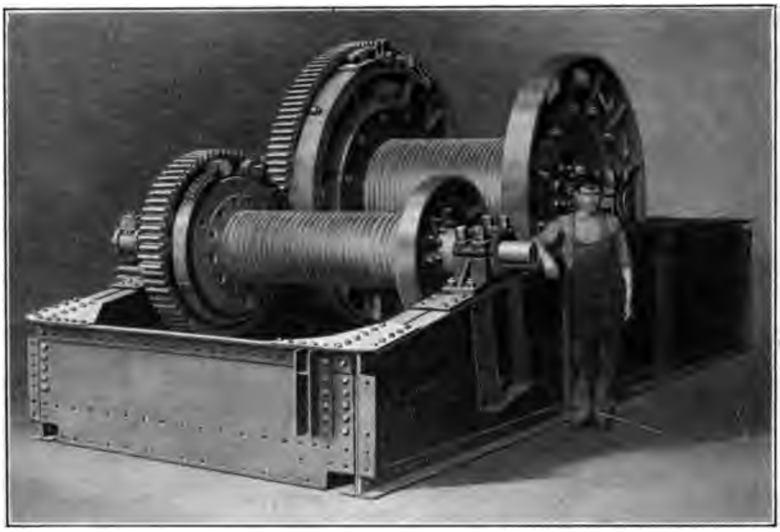


FIG. 17.—Hoisting and Backing Drums—14″ × 16″ dipper dredge. (*Courtesy the Bucyrus Co.*)

the cranesman releases the stick, which shoots up through the boom. The runner swings the boom until the bucket is suspended over a pocket of the scow and the cranesman pulls the latch string, dumping the bucket.

Application of the Type.—To the need of the American contractor for a simple, inexpensive and versatile machine, the dipper dredge owes its rapid development in this country. It is very efficient in hard material, provided the depth is not excessive, and is used to advantage in canal work through solid ground containing stumps and roots, in the dredging of previously blasted or loose rock

FIG. 18.—U. S. dredge Paraiso (Bucyrus Co.) bringing up a 50 ton boulder from the bottom of Culebra Cut. (*Courtesy the Bucyrus Co.*)

and in the removal of old filled cribs, old foundations, sunken wrecks and stone dikes. Thus it is a most capable machine, with a wide application. The conditions of uniformly hard materials and moderate requisite depth of channel on the Great Lakes have occasioned an extensive use of the dipper there.

High-powered Dipper Dredges.—The earliest dipper dredge of large size was the 12 yard machine ONONDAGA, owned and operated in New York Harbor about 1904 by the contractors Hughes Brothers & Bangs. Since then, and prior to 1904, the largest exponents of the type were probably the two 10 yard machines used on the Cape Cod Canal, built by the Atlantic Equipment Co., and the 15 yard dredge TOLEDO, built by the Bucyrus Company.

At the time of the closing of the Panama Canal by the first large slide, the largest dippers in use there were 5 yard. It was decided that the only type of machine suitable for the removal of this huge mass of broken rock and earth, containing pieces of rock of all sizes and lacking all uniformity of formation, was a large capacity and high-powered dipper dredge. The decision resulted in the construction by the Bucyrus Company of three 15 yard dipper machines, the GAMBOA, PARAISO and CASCADAS, the latter being the last built and arriving at the Isthmus in October of 1915. Although open to criticism perhaps as to the abnormally high cost of maintenance, attributed by some engineers to defects in the main hoisting wires, the dipper arms and the spuds, both the builders and the management were justified by the splendid performance of the machines and by the fact that the first two were in large part copies of the TOLEDO because of the lack of time to prepare new designs. Each of the three dredges had a demonstrated capacity of more than 3,000,000 cubic yards per year. They are all pin-up machines, with steel hulls. The principal statistics of the above dredges are given in the Table, page 45.

	ONONDAGA	GAMBOA & PARAISO
Hull length	140′	144′
width	50′	44′
depth	15′	13′–6″
Main Engines—Type	Double cylinder condensing	Compound
Size	20″.5 × 24″	16 and 28 × 24
Forward Spuds—Material	Oregon Fir	Structural Steel
Section	5′ × 5′	4′ × 4′
Length	80′	82′
Dipper Arm—Material	Oregon Fir	Long Leaf Y. P.
Section	3′ × 3′	
Length	80′	72′
Capacity of Dipper	15 cu. yd.	Rock 10 cu. yd. Mud 15 cu. yd.
Max. Working Depth	50′	50′
Bail Pull		235,000 lbs.

N. B. The CASCADAS differed principally in the width of hull, which was 55 ft., in the depth, 15′–6″, and in the use of a gallows frame to raise the spuds without the use of sheaves in the spud toes, which proved objectionable because of the cable abrasion due to the rock. Several improvements were also made in the machinery and in other details as dictated by the experience with the other two.

CHAPTER IV

LADDER DREDGES

Historical.—The ladder or elevator dredge is distinctly a European product and, until recently, has found little favor in the United States for major dredging projects. The reason lies not so much in the qualities of the dredge itself, but rather in the quite opposite methods of administration of port development of the two continents. Mr. A. W. Robinson, in his paper on the "Review of General Practice," printed in Vol. LIV of the Transactions of the American Society of Civil Engineers, 1905, writes: "In America, the opening up of a vast, virgin country, both on the seaboard and in the interior, required the rapid execution of a great number of works suited to immediate necessities, under the small contract system. This system has given rise to a class of contractors of all grades, who build and own their plant, and as their contracts are liable to be varied both as to locality and conditions, they do not invest largely in special plant. The small contractor . . must employ a plant which is adapted to a variety of work, and which does not represent more capital invested than his contract will warrant. . . . On the other hand, the large corporation, or Board of Harbor Trustees, under the European method of administration, is able to lay out a comprehensive plan of the works under its charge and provide permanent plant adapted to it, which will be assured of employment through a series of years. This has developed the large and complete seaworthy dredge of the ladder and bucket type, which is found so frequently in Europe and so rarely in America."

The inexpensive and versatile dipper dredge, therefore, was early and rapidly developed in this country, proving an excellent tool especially for harbor and shallow work as

FIG. 19.—The Alfred E. Hunt—St. Lawrence River Power Co., Massena, N. Y. A 15 cu. ft. ladder dredge, driven by two 300 h.p. motors. The dredgings are screened and pumped ashore through a pipe line by a 24 inch centrifugal pump. The oversize is deposited into a scow. Shown working in glacial drift consisting of boulders and cemented gravel. (*Courtesy the Bucyrus Co.*)

found in the Great Lakes, and the grapple dredge attained equally rapid development on the softer tidal work of the Coast, and both to the almost absolute exclusion of the ladder or elevator type.

In more recent years, however, the tendency has been to the design of machines of larger capacity, in the belief that their lower unit cost of output justifies the greater initial outlay. This trend, together with the attention demanded by the ladder type in its economic performance on the Panama Canal, has led to a more general acceptance in this country of the advantages of the elevator dredge, as is evidenced by the purchase in Scotland of a large machine of this type for use on the Panama Canal. The capacity of each of the soft-digging buckets of this dredge is 2 cubic yards, and of the hard-digging, 35 cubic feet.

Moreover, in Canada, on the St. Lawrence River Ship Channel, the ladder dredge has been in active use for years, even antedating the development of the dipper. The type secured a foothold in Canada from early examples imported from Scotland, and, because of its adaptability both to the local dredging conditions and to the method of government operation through a number of years, its popularity there has persisted.

It is now generally conceded that the very hard, indurated clays, shales, soft rock formations and hard-pans, when excavated in their original condition without previous blasting, are most economically dredged by ladder machines and that, in hard clays, the choice between the ladder and the dipper is difficult, except as determined by depth of water and depth of cut.

The ladder dredge of the so-called "stationary" type has found favor for some years in two American industries, viz. dredging for gold in the western states with the large placer, elevator machine, and for commercial sand and gravel. The peculiar virtues of the type, to which it owes its superiority for gold dredging, are the clean pick-up of the gold bearing gravel with a minimum of agitation and the delivery to the screen of an almost continuous stream

FIG. 20.—15-foot Bucyrus placer dredge, Natomas Consolidated, of California. (*Courtesy the Bucyrus Co.*)

without leakage. The failure of other types of dredge in these two essentials, resulting in an excessive loss of gold, has militated against their employment in the industry.

In Chapter IX, under the caption "Choice of Plant," American and Continental opinion upon the relative merit of the ladder dredge is further cited.

General Description.—The digging mechanism of the ladder dredge consists of a long trussed ladder, inclining from the top of a tower through a slot or well in the hull down to the mud line; a series of buckets traveling in endless chain succession up the top side and down the lower side of the ladder, and carried by two tumblers or drums at the two extremities thereof and by rollers upon its upper face; and the main engine actuating the upper tumbler, which engages the endless bucket chains. The ladder may be raised and lowered, pivoting about the tower top. The buckets obtain their loads by scraping along the bottom in the act of revolving about the lower tumbler, and discharge when they invert at the upper or driving tumbler, which is driven by the main engine through chain or belt, or more commonly through gears and a friction clutch. This last is intended to safeguard the engine against possible sudden shock due to abrupt resistance or impact of the buckets. The velocity of the bucket travel is varied to meet the conditions of material and depth, preferably through the gearing independent of the main engine. It is essential that the dredge be equipped with two sets of buckets, one for hard and the other for soft digging. They vary in size generally from 5 cu. ft. to 1 cu. yd. capacity. The soft digging buckets are larger for the same machine than the hard digging, and are re-enforced on the cutting edge with hard steel lips. The buckets designed for hard material are heavily constructed and are provided with teeth at the lip. Both digging and discharging are facilitated by tapering the buckets in longitudinal section both vertically and horizontally.

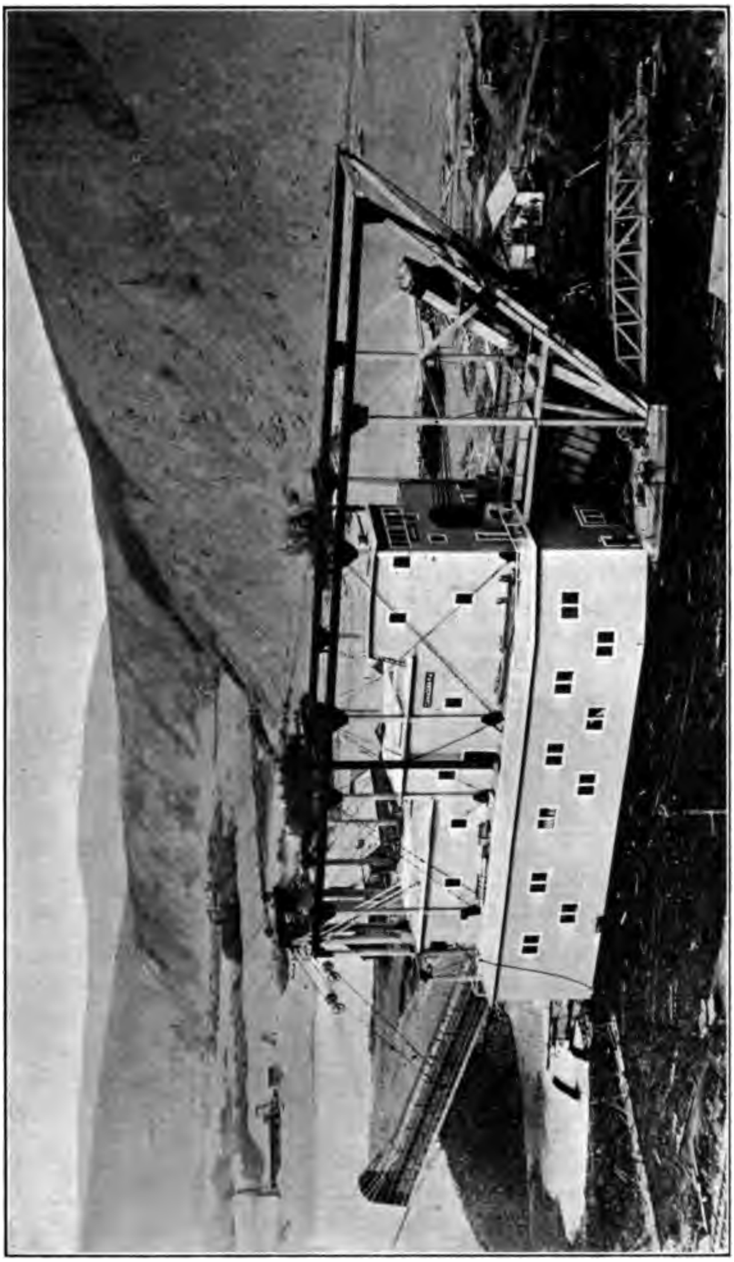


Fig. 21.—16 cu. ft. placer elevator dredge, Canadian Klondyke Gold Mining Co. Electrically driven; ladder 97 ft. long with 71 buckets of 16 cu. ft. capacity each; maximum digging depth 40 ft.; wooden hull, 136 ft. × 56 ft. 8 in. × 14 ft. 6 in.; main motor 300 h.p. *(Courtesy of Marion Steam Shovel Co.)*

Stationary Type.—The hull of the stationary type is generally rectangular both in plan and in cross section, pierced with a well or slot through which the ladder operates. The feeding movement is either lateral through the agency of six mooring cables to as many anchorages, or radial, the dredge pivoting about a stern spud in the manner of the radial-feeding hydraulic machine. American practice tends toward the latter method. The objection to the former and an argument in favor of the self-propelled type is the obstruction presented by the cables to river traffic. The St. Lawrence River dredges are of the lateral feed type, making a cut as wide as 750 feet in one operation, the extensive movement being permitted by exceptionally long head lines of wire rope carried on floats for a considerable distance ahead of the dredge to obviate the resistant dragging on the bottom.

The dredged material is conducted to scows moored to the dredge through chutes leading from the receiving hopper at the top of the tower. Machines operating in a mixture of sand and gravel for commercial usage, contain a cylindrical rotating screen at the top which segregates the material so that sand is discharged into a scow on one side of the dredge and gravel into a second scow on the other side. Some dredges have abnormally high towers and long chutes supported from the dredge, depositing the dredgings at some little distance. Flow in the chute pipes is sometimes accelerated by pumping water through them. When it becomes necessary to transport the material to points more remote from the dredge, floating pipe lines are employed, through which the material is forced by water from a discharge pump. In some instances, a series of belt conveyors mounted on lighters has been used.

Sea-going Hopper Type.—The sea-going ladder dredge is a self-propelling steamer, with moulded hull and self-contained hoppers. When loaded, it travels to the dumping ground under its own power and discharges through doors at the base of the hoppers. They are usually of the twin-screw type, driven either by the main dredging

engine or by an independent unit. It is customary to provide for discharging both into the dredge hoppers and into hopper barges moored alongside.

Dredges of this type vary through wide limits as to size, capacity and maximum depth of dredging; in length from about 130 to 275 feet; in hopper capacity from about 500 to 2200 tons; and in greatest possible depth of dredging, from about 30 to 50 feet. The previously mentioned machine, purchased in Scotland by the Isthmian Canal Commission, has a specified capacity of 1200 cubic yards of mud or sand per hour, and a maximum dredging depth of 50 feet. The speed of sea-going ladder dredges is generally from 6 to 8 miles per hour, when loaded.

While the stationary machine may have two ladders, one on each side, the sea-going dredge, for reasons of stability, has but one on the longitudinal axis of the hull. The tower is erected amidships and the well may be either forward or aft. There are two types of well, the close-ended and the open-ended. The latter is more commonly used, due to the advantage of being able to dig flotation for the dredge. General practice employs the bow well for single-screw steamers and the stern well for twin-screw. The well is proportioned to the length of the ladder. In the bow-well dredge, the ladder, when raised, lies wholly within the well, and a breakwater is installed at the after end of the well to deflect the water under the keel of the vessel when steaming ahead.

The length of the ladder should be such as to reach the maximum required depth when at an inclination of 45 degrees, since the maximum amount of work is said to obtain at that angle. Some designers have even gone so far as to build the ladder in two parts, so that the lower section may always have a slope of 45 degrees.

For the sea-going ladder dredge, the advantage is claimed of entire seaworthiness in ocean dredging and the absence in rough water of the pounding of attendant plant, so destructive both to such plant and the dredge itself. It is open to the criticism, however, of intermittent dredging operation due to the frequent trips to the dumps.

CHAPTER V

SCOWS

The most common conveyance for the transportation of dredgings (pumpings excepted) is the bottom-dump mud scow. It is in effect a hopper barge, without means of self propulsion, consisting simply of a hull rectangular in plan and cross section, containing a number of independent hoppers called pockets, and with both ends raked or rounded (in elevation) for towing in either direction. Roughly, it is somewhat more than three times as long as it is wide, and the depth of hull from deck to bottom planking is about one-third of the beam. When light, it has considerable freeboard, but when fully loaded, it floats with decks awash, the material being retained by the pocket "coamings"—a name given to the portions of the pocket walls projecting above the deck. The coaming height is usually from two to three feet.

The common form of cross section is shown in fig. 22. Neglecting the fore and after holds, between the ends of the scow and the faces of the first and last pockets, the vessel is dependent for buoyancy upon the polyhedral spaces between the sides of the scow and the sloping side walls of the pockets, unless the continuity of the pockets is broken by one or two transverse holds, as is sometimes done, not merely to increase the displacement, but also to add to the transverse strength. Thus, the displacement tonnage per inch immersion decreases quite rapidly as the draft increases, and the loaded scow has no reserve buoyancy. While these two features may appear objectionable, and while we do hear, occasionally of the capsizing of a mud scow, yet the good points of the design are so preponderant and the disaster of capsizing so trivial that the popularity of the type lives on.

It will be remembered that mud scows are loaded, not as the designer would have them for minimum stresses in the structure, but from one end to the other, and that usually they are dumped in the same way. Obviously the resultant tendency is to "hog" the scow, i. e. by negative bending moment in the structure as a whole, to render it convex upward. To provide adequate stiffness longitudinally, therefore, a pair of strong trusses are built in the plane of the side coamings for the full length and depth of the scow. In timber scows, they are generally of the Howe type. Supplementing them, the sides of the

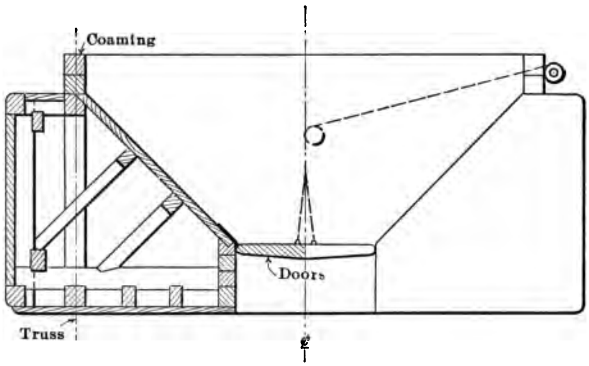


FIG. 22.—Cross section of the common, bottom-dump mud scow.

vessel are detailed to further resist the "hogging" strains in that the upper strakes are in long lengths and spliced with long *tension* scarf joints. The lower strakes are as a rule framed with long scarf joints without the tension feature. The intermediate courses may be butted at stanchions. The truss rods should be provided with turnbuckles, that they may be adjusted to timber shrinkage and local fibre crushing. The transverse strength of the scow is provided by the walls between pockets, which are solid bulkheads extending the full width of the ship.

The floor of each pocket consists of a pair of doors, hinged at the sides to open downward at the centre. A chain at each end holds them horizontal or closed, running through a lead chock to a shaft just outside the coaming.

Upon this the chain is wound by lever bar, ratchet wheel and pawl. Each pocket has its own gear and is dumped independently of the others, by pounding the pawl out of engagement with the ratchet wheel, whereat the chain is released, the doors fall open and the load drops through. Although not always feasible, it is desirable that the depth of well below the door hinges be equal to the width of a single door, in order that the doors when open may not project below the bottom of the scow, in which position they are liable to damage in shoal water.

Whatever the material of which the scow is constructed, it should be strongly and durably designed, to withstand the severe treatment necessarily meted out to it. Although steel has been used in some instances, timber appears to be best adapted to the purpose and is quite prevalent. Current practice builds the body of the scow of long leaf yellow pine, of prime inspection, with corners and deck strake of white oak. The corners are armored with steel plates. The scow is always moored to the dredge with the shaft and winding gear on the side remote from the dredge, so that the danger of damage to the gear shall be reduced to a minimum. The coamings on the port side, therefore, are fitted with eye-bolts at each pocket to receive the hook of the breast line from the dredge. Consequently, it is the port coaming and the port side of the hull that wear most rapidly, due to the destructive impacts of the bucket. For this reason, the port side is not uncommonly sheathed with 2 or 3 inch oak or pine, preferably the former. Sometimes the two ends are protected likewise, and in teredo-infested waters, such sheathing on all sides is of paramount importance. The scow is equipped with towing bitts, and with hatches for ventilation and siphoning out fore and aft.

For river and harbor work, scows of 500 or 600 yards capacity are the most popular. Larger sizes present the objectionable features of great freeboard when light, requiring an inordinately high bucket lift, and great draft when loaded, requiring deep water for dumping. The latter becomes an important factor in dumping to a hy-

draulic machine for pumping ashore. In this instance, the so-called rehandling basin, or rectangular hole excavated by the pumps to receive the dumped material, is located preferably as close to the impounding basin as the consideration of minimum depth for dumping scows will permit, the idea being of course to reduce the length of discharge pipe line to a minimum. Hydraulic dredges engaged in rehandling work are required to maintain a depth in the rehandling basin at least as great as the surrounding depth, in order that as little material as possible shall be lost between dumping and pumping. The limits of the rehandling basin are defined by ranges to control the operation.

Scows of types other than the bottom-dumps are in less common use for handling dredgings. For rock and commercial sand and gravel, deck lighters are employed. Particular attention must be given here to the design of the deck for the heavy loads and impacts. For rock, a layer of sheathing is usually laid on the deck planking. Concrete deck scows have been successfully used for sand and gravel. Deck lighters may be converted into mud scows by erecting on the deck a series of gable bottom bins, with the ridge in the plane of the longitudinal axis of the hull, and discharging through vertical doors on both sides. Such an arrangement is particularly adaptable to shoal water, although the centre of gravity of the loaded scow is abnormally high, and dumping at times proves a rather delicate operation. A second method of rigging deck scows to discharge their loads is by the use of a sliding deck platform mounted on rollers on a slight incline. This false deck when loaded and unlatched slides to one side by gravity for a distance of several feet, when it is checked by a stop. The momentum of the load and its eccentric position cause the scow to list until the material slides off into the water, whereupon, the scow, released, rights itself.

For towing to sea, large dump scows, upwards of 2000 yards capacity, have been used, and in some instances self-propelled hopper barges have been employed to transport dredgings.

CHAPTER VI

HYDRAULIC DREDGES OF THE RIVER TYPE

As outlined in Chapter I, there are two general and distinct classes of hydraulic dredges, the *River Type* and the *Sea-going Hopper Dredge.* The first is the smaller machine, built for use in the calm waters of rivers and sheltered harbors, and is rarely self-propelling except among those designed by the Mississippi River Commission to meet the special and unique conditions obtaining upon that mutinous water-course. The second is the more imposing, ocean-going steamer, with moulded hull and, in the great majority of cases, with self-contained hoppers for receiving and transporting the pumpings. Although at times economically adaptable to ship-channel work in rivers and harbors, it is primarily intended for the removal of obstructive ocean bars.

The type of dredge developed by the Mississippi River Commission under the direction of the U. S. Government, embodies many distinctive features, by virtue of which it has been isolated in the foregoing classification and will be discussed subsequently in this chapter. The text immediately following refers only to the

Radial-feeding Dredge with Spud Anchorage

General Description.—Briefly, it consists of a centrifugal pump directly connected to a steam engine or a motor and mounted on a hull equipped with a hinged ladder, carrying both suction pipe and cutter-head, and with some means of position control and feeding movement.

The dredge may be said to have three principal functions; first, the breaking up or cutting of the bottom material so that it readily may be drawn into the suction pipe; second, the horizontal and vertical movement of the suction pipe

and cutter so that the material may be fed constantly to the suction; third, that of pumping the material through suction pipe, pump and discharge pipe into the spoil basin or the adjacent deep water. The first is accomplished by means of a rotating cutter at the suction end of the ladder, keyed to a shaft carried on the ladder and driven by an engine, called the cutter engine, located at the ladder hinge. The vertical movement of the second function is obtained by boom, "A" frame, back guys, fall and hoisting engine, by which the ladder is raised and lowered.

FIG. 23.—The Pennsylvania—American Dredging Co.

The horizontal movement, laterally, is effected in one of two ways; either by swinging the dredge and ladder as a whole about one of the two stern spuds as a pivot, or by swinging the ladder only, the dredge being held by three or four spuds. The forward movement or the "advance in cut" is obtained in the first instance by the alternate use of the two stern spuds and, in the second, by "walking" spuds. The third function is accomplished by the pump and its drive with the appurtenant suction pipe, floating discharge pipe or pontoon line, and the shore pipe-line.

All operations, with the possible exception of the spud hoists, are controlled from the pilot house or lever-room. The "runner" or "leverman" faces the suction end and is

guided in his manipulation of the dredge by pressure, vacuum, steam and depth gages and by the behavior of the cutter engine.

The size of the pump varies from twelve to forty-eight inches, but the twenty inch dredge is generally conceded the most advantageous for all around work. Twelve and fifteen inch dredges are useful for dredging in confined areas and for pumping into basins of small capacity, or into

FIG. 24.—The Tampa—Atlas Dredging Co., New York.

filled piers or behind bulkheads. The larger sizes are well adapted to the removal of silt and fine sand and to the rehandling of material previously excavated by bucket dredges and dumped from scows to the hydraulic dredge to be pumped ashore.

Figure 23, Page 59 is a photograph of the thirty inch dredge PENNSYLVANIA, of the American Dredging Company, of Philadelphia, and is a good example of the swinging ladder type with walking spuds. This dredge has been used exclusively for rehandling dredged material, and has pumped as high as 753,000 cubic yards of mud in one month, working 24 hours per day.

Figure 24 Page 60 is the twenty-two inch hydraulic dredge Tampa of the Atlas Dredging Company of New York City. It is a powerful machine of the swinging-

dredge type and performed yeoman service in the removal of a heavy mixture of mud, sand and some gravel incident to the construction of the Hog Island Shipyard.

FIG. 25*a*.—The open or cage cutter. (*Courtesy of Marion Steam Shovcl Co.*)

FIG. 25*b*—The closed or round-nose cutter. 30 inch, light type. (*Courtesy of Bucyrus Co.*)

Cutter Head and Ladder.—There are two principal types of cutters, the open or cage type as shown in Figure 25*a*, Page 61, and the closed or round-nose cutter as illustrated in Figure 25*b*. The former consists of a set

of knives or blades, straight or nearly so, mounted on a pair of annular frames of different diameters so that the blades converge outboard. The blades are set at an angle of from 15 to 25 degrees with the cutter head axis or shaft and protrude a short distance beyond the end frame. The great wear caused by the excessive abrasion makes it advisable that the blades be independent of the frames to facilitate renewals. In the closed or round-nose cutter, the blades are spiral shaped and converge to a hub at the nose or outboard end into which the end of the shaft is fitted. In both types, the cutter shaft is set immediately above the suction pipe, the end of which must, of course, lie within the surface described by the cutter blades. The large diameter of the cutter-head, therefore, will be somewhat greater than twice the outside diameter of the suction pipe.

The relative merit of the two cutters will vary with the character of the material and even more perhaps in the judgement of dredging men. Mr. Charles Evan Fowler, in his "Subaqueous Foundations" writes "The round-nose type is best suited to soft material, but usually the ordinary inward-delivery cage cutter is to be preferred especially for the compact and harder materials." If working in clay, a cutter with a relatively large number of blades closely spaced has a tendency to retain the clay within itself, finally becoming entirely choked with the sticky mass.

To exclude stones and other obstructions, various straining devices are used. The cutter becomes a strainer when fitted with a series of bands or rings at the blades in planes perpendicular to the shaft, resulting in a cage-like structure, admitting only such objects as are smaller than the trapezoidal openings between the blades and the transverse rings. The material is excluded from the rear or large end of the cutter either by a transverse screen or by a solid disc, which completes the closure partially effected by suction pipe and ladder. Another scheme involves the use of a circular transverse screen or grating

set in the big end of the cutter, perpendicular to the shaft and a short distance in front of the end of the suction pipe. It is attached to the cutter and rotates with it, resulting in the continual procession of the strainer openings across the mouth of the suction. It is apparent that any long and narrow obstruction, such as a stick of wood or a long stone, passing through one strainer opening and protruding into the suction pipe would be subjected to considerable

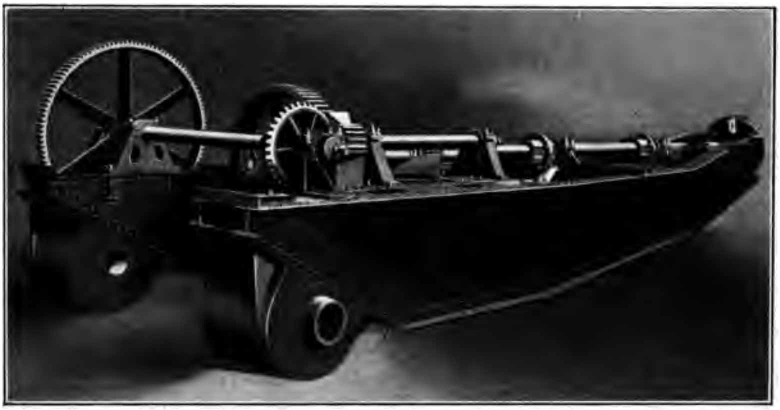


Fig. 26.—Ladder and cutter machinery for 20 inch dredge. Extra heavy. (*Courtesy the Bucyrus Co.*)

shearing strain and would cause high stresses in the strainer, cutter and shaft. It is well, therefore, generously to proportion these parts that they may be capable of stalling the cutter engine without overloading themselves.

The cutter shaft is of relatively large section (about eight inches for a twenty-inch dredge) because of the torsional stresses set up in it by the maximum moment of which the cutter engine, through its gears, is capable. It is carried on pillow block journals set on the top face of the ladder.

The ladder may be a heavy steel box girder enclosing the suction pipe; or a pair of plate girders braced together; or a pair of lattice trusses. The last mentioned type offers less resistance to the current and is on that account better adapted for use in swift streams. In swinging dredges,

the ladder's perpendicularity to the bow is maintained by guy rods to the forward corners of the hull, or by spreading the two girders forming the ladder so that it is triangular in plan, or by a combination of these two methods. The stresses in the ladder are due to the pull of the swinging wires, the reaction of the rotating cutter, horizontal and vertical hull movement when the cutter head is in the mud and finally to the upward pull of the fall from the boom in raising the ladder and the dead weight of the ladder itself. The ladder is set in a well or recess in the center of the bow of the dredge. In the case of the swinging ladder dredge this joint must permit both horizontal and vertical motion of the ladder with respect to the dredge, but in the swinging dredge vertical motion only is required. If the outboard end of the latter is guyed to the hull corners, the points of attachment of guy rods must be in line transversely and vertically with the center line of the hinge.

The maximum depth below the water surface to which a hydraulic dredge can dig is determined by the length of the ladder and the hinge construction. Ladders 70 feet in length are not uncommon, permitting dredging to a depth of about 45 or 50 ft. below the water.

Feeding.—The arrangement of spuds depends upon the method of feeding. The case of the swinging dredge will be first considered.

It has but two spuds set in the same transverse plane at or near the stern of the dredge, about 10 or 12 feet apart and, if the discharge pipe is centered in the hull, symmetrical with respect to the dredge axis. If the discharge pipe leaves the hull at a point near a stern corner, the spuds are set off center in the direction of that same corner, in order that the point of attachment of pontoon line to dredge shall be as close as possible to the center of rotation to minimize the effect of the rotation upon the alignment of the pontoon line. When working, one spud is always up, clear of the bottom and the other down in the mud, forming the pivot about which the dredge rotates or swings. This radial motion is effected by two swinging wires, extending from

two anchors, one on each side of the bow, to the winding drums on the dredge. The pull of the wires may be applied by means of sheaves to the outboard end of the ladder near the cutterhead, to the bow corners of the hull or to a kind of triangular horizontal apron extending forward from the bow. The first method has the advantage of keeping

FIG. 27.—The cutter-head at work. (*Courtesy the Bucyrus Co.*)

the swinging wires down on the bottom out of the way of passing vessels but presents also the disadvantage of the possibility of entanglement of the slack swinging wire about the cutter in the event of careless operation. When it becomes necessary to advance the dredge in order again to thrust the cutter into the bank, the movement is accomplished by dropping the high spud and raising the other when the dredge has swung to the limit of the cut. Thus,

the new pivot is further ahead in the cut and the center of rotation therefore, advanced. In this manner, the dredge moves ahead, by the alternate use of the two spuds, successive positions of which, if plotted and joined by straight lines, would form a series of saw teeth.

The swinging-ladder dredge has four spuds, two forward and two aft, all of which are in the mud while pumping. Thus the hull is held, while the ladder is swung by means of swinging wires from cutter head to winding drums after passing through guide sheaves at the bow corners. At least three of the four spuds are set in slotted wells, permitting them to incline forward from the vertical and are called "walking spuds." Two wires extend from the two forward spuds at or near their toes to sheaves on the stern corners of the hull, thence to drums of the winding engine. To move ahead, these wires are wound on the drums, pulling the dredge forward and inclining the spuds. When desirable, the walking spuds can be raised and plumbed, one at a time. Such dredges usually are equipped with a stern wire for hauling astern. Obviously, the swinging-ladder dredge makes a much narrower cut than the swinging-dredge and can, therefore, work in more confined spaces. Further more, the absence of side wires is often an advantage as they interfere with traffic in the vicinity of the dredge. On the other hand, the total time lost in moving and shifting the dredge is greater for the swinging-ladder type because it covers less area with one set up.

It is well to remember that the stress in one swinging wire is nearly always greater than in the other, due to the fact that the rotation and, therefore, the reaction of the cutter is always in the same direction, which fact at times becomes a factor in locating the dredge to the best advantage.

Boom "A" Frame and Back Legs.—Boom and "A" frame are set well forward, the former at a fixed angle of from 30 to 45 degrees with the horizontal, the latter generally vertical. The ladder is suspended from the boom head by a wire fall, which is purchase rigged to the ladder

near the cutterhead and partially bridled to relieve the bending stresses in the ladder. The purchase retards and eases the vertical motion and at the same time economizes in engine capacity. The boom may be a single strut, or, in dredges that swing as a unit, it may be, in plan, an acute "A" frame to prevent lateral movement. The boom of the swinging-ladder dredge necessarily swings with the ladder, its heel, therefore, being mounted upon the same rotating bearing that carries the ladder trunnions. The "A" frame varies greatly in design from the ordinary timber type to steel frames of rectangular and even polygonal outline. The stresses in boom, "A" frame and back-legs or guys may be obtained graphically, knowing the maximum pull of the ladder hoisting engines, the purchase ratio and the angles of lead. The "A" frame and back-guy stresses will be greater in the swinging-ladder type than in the swinging dredge, becoming maximum for the same positions of the boom as outlined under grapples.

In some dredges, built for use in localities where head room is a consideration, such as in canals with limited clearance under bridges, the boom angle is quite flat and the topping-fall almost horizontal, and at about the same elevation as the roof of the house, which is but one story high. A house boat is generally an indispensable adjunct to such dredges as there is no space for living quarters on the dredge. A notable example of this is afforded by dredges used in the construction and maintenance of the New York State Barge Canal.

The Pipe Line.—The total length of discharge pipe line comprises three distinct parts; First, the portion on the dredge from the pump to the point of leaving the hull; second, the floating or pontoon line; and, third, the shore line. Since the first constitutes a permanent integral part of the dredge and also because any break therein might flood the hull and sink the ship, it is made of heavy cast iron pipe with flanged joints. For the usual central transverse position of the pump, there are three principal methods of discharge pipe arrangement resulting in three

possible locations for the point of attachment of the pontoon line. Referring to Figure 28, they are No. 1, a direct lead from the pump to the side of the hull; No. 2, a stern discharge near one corner; and No. 3, the axial stern location. No. 1 discharge is limited to the swinging-ladder dredge, since in the swinging dredge type it is essential that the point of connection of pontoon line to dredge be close to the spud about which the dredge rotates. Location No. 3 presents the objection of loss of head due to reverse curvature. For general use, Discharge No. 2 appears to be preferable. Some swinging-ladder machines are equipped to discharge either at the stern or side, com-

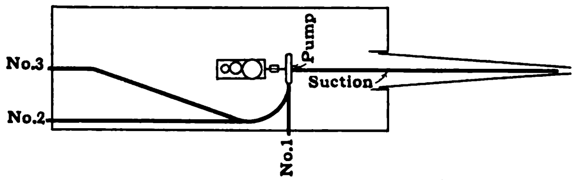


FIG. 28.—Discharge pipe arrangements on the dredge.

bining Nos. 1 and 2, or 1 and 3. The precaution is sometimes taken to enclose the pump in a watertight trough so that, in the event of a break in the pipe, the hull will not be flooded. Location No. 2 is particularly adapted to this safety measure in that the side of the hull and the adjacent longitudinal bulkhead form the two sides of such a trough and easy access may be had to the pipe so located by substituting removable hatches for the deck over the pipe.

The floating line from the hull to the shore pipe consists of a series of pontoons, each carrying a section of pipe from 20 to 50 feet long, so coupled to each other as to provide the necessary flexibility to allow the dredge to swing and advance or, in other words, to "wag her tail." Both pontoon and shore pipe are lap or spiral riveted, usually the former, the sheets varying in thickness from No. 10 gauge to ⅜ inch. The shore pipe is built in sections of such length as to preclude a weight too great for handling by manual labor alone. They are seldom greater than

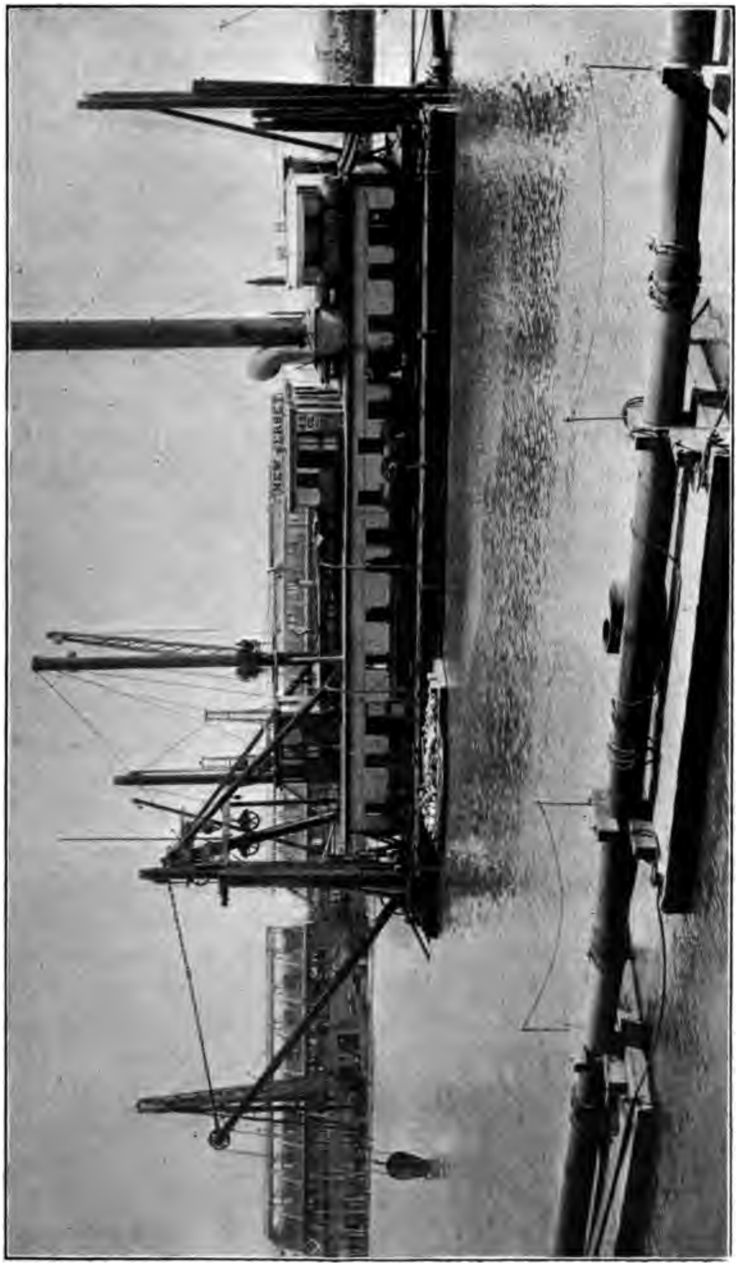


FIG. 29.—The New Jersey and pontoon line—American Dredging Co.

20 feet long and frequently only 16 feet. The pontoon pipe, however, is built in long lengths to reduce the number of couplings and pontoons and is usually of heavier metal. The sections of the floating line are coupled either by heavy, rubber sleeves or by ball-joint connections. Because of the short life and expense of the rubber sleeves (they are seldom less than 10 ply) the ball joint method is more economical. The shore pipe is laid with slip joints, the male end of each length protruding into the female end of the next in the direction of flow, and wired together, a pair of hooks being riveted to each end of each section for this purpose. Leaks in such unions are almost the rule rather than the exception and are plugged by wedges made from wooden shingles or equally convenient shapes. In tide water, the varying elevation of the pontoon line with respect to the shore line is permitted by a ball-joint pipe.

The most common fittings used in connection with dredge discharge pipe are bends, elbows, "Y"s and gate valves. The necessity often arises for sharper curvature in the pontoon line than is permitted by the couplings and it is met by the insertion of one or two elbows in the line. The shore pipe deviates from the straight line in circumventing obstructions and in continual shifting of direction in the basin to control the elevation of the fill. Although the slip joints allow a certain amount of curvature, bends of 15 degrees and up are often essential fittings. In order to facilitate the addition of pipe sections in the basin without stopping the pump, it is common practice to divide the line into two branches by means of a "Y" and two gate valves at a point on the fill near the discharge, with the idea that one leg of the fork can be lengthened while pumping continues uninterruptedly through the other. For this to be a true economic advantage, it is apparent that the loss of head due to the fittings must be fully offset by the prevention of lost pumping time.

There are several types of pontoon, which may be designated as the "scow" pontoon, the "catamaran" pontoon and the "cask" pontoon. The first is simply a single box

of wood or steel, rectangular in plan and section. The second consists of two long narrow floats, either steel cylinders or wood boxes, with their longitudinal axis perpendicular to the pipe mounted upon them amidships. By struts from one to the other of each pair, they are maintained at such a distance apart as to place one near each end of the pipe section. In the "cask" pontoon, the pipe rests upon a horizontal frame to the under side of which a number of strong barrells or large kegs are fastened, providing

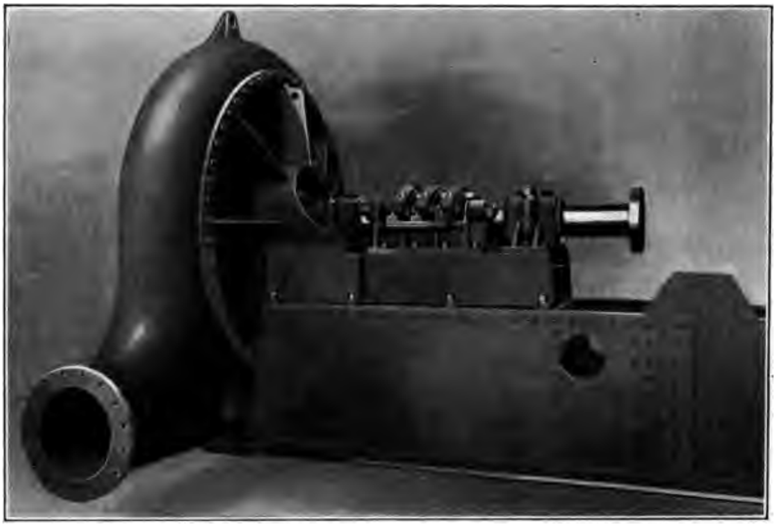


FIG. 30.—The pump and thrust bearing. (*Courtesy the Bucyrus Co.*)

the requisite buoyancy. For the convenience and safety of the crew and pipe gang, it is desirable to provide a continuous walkway on the pontoons parallelling the pipe.

The Pump.—Centrifugal pumps, as used for dredging, have the following features: They are *horizontal* pumps, i.e., the shaft is horizontal. They are *high pressure* pumps, i.e., the head for which they are designed is greater than 50 feet. They are *single stage* pumps, i.e., the head is generated by one impeller only. They are *single inlet* pumps, i.e., the water enters the impeller on one side only, necessitating the interposition of a marine thrust bearing

between the pump and its drive. They are *backward-discharge* pumps, i.e., the impeller tips are bent backward and the angle Θ, Figure 31, Page 72, between the absolute velocity of exit of the water, V_1, and the peripheral velocity of the impeller, V_2 is greater than 90 degrees. This type of pump is the most common even in water pumps and, because the head decreases as the quantity increases, it is better able to take care of a fluctuating quantity without overloading its driver. It is this feature principally which makes it the most desirable type for dredging purposes.

There are no discharge vanes in dredge pumps.

The impeller is of the enclosed type. The open type, due to rapid wear, loses in efficiency.

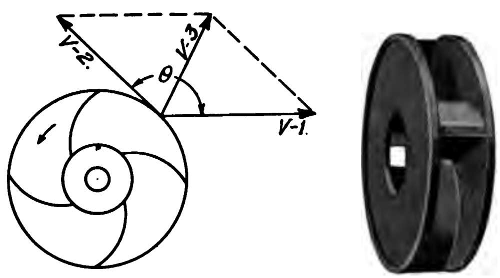


Fig. 31.—Dredge pump impeller or runner.

The openings between blades and between the periphery of the impeller and the shell are large to permit the passage of large objects such as stones, short timbers, etc. The pump must be designed to take anything that can pass through the cutterhead and into the suction. Chokes in the pump involve loss of time and possibly serious damage.

Both impeller and shell are heavily proportioned to withstand the abrasive action of the pumpings. It is good practice to use an unlined pump of very heavy proportions fitted with lined side discs.

Shell and impeller are cast iron or cast steel.

The problem is to design a pump to stand the unusually severe wear and tear, to pass fairly large bodies, and yet

be of reasonable efficiency. It is apparent that the efficiency of a dredge pump cannot be as high as that of a water pump, and seldom exceeds 50 per cent.

The total head to be overcome by the pump is the sum of three components: first, the suction head; second, the height through which the discharged pumpings are raised, which may be termed the elevation head; and third, the friction head, or the frictional resistance offered by the pipe to the passage of the pumpings. The pump, therefore, must create a partial vacuum in the suction pipe in order to give to the entering water a high velocity, sufficient to draw in the material and to keep it moving and must also produce the pressure necessary to force the water and material through the discharge pipe against the resisting elevation and friction heads. Twenty-inch pumps have been designed capable of elevating the pumpings to a height of 40 feet through 3,000 feet of pipe line.

The suction head is the amount of vacuum in the suction pipe and is read on the vacuum gage in the lever room of the dredge. This gage is usually calibrated in inches of mercury, i.e., the barometric column. Its readings may be converted into feet of water by multiplying by the constant 1.13 which figure is the ratio between the weight of a column of mercury one inch high and a column of water one foot in height, since the specific gravity of mercury is 13.56.

The elevation head is the vertical height from the center of the pump to the highest point in the discharge pipe line. The sum of the friction and elevation heads is obtained from the discharge pressure gage in the lever-room. The reading is in pounds of pressure per square inch and may be converted into feet of head by multiplying by the constant 2.304. As this gage is usually some distance above the center of the pump, the head represented by the gage reading must be increased by this distance in order to get the actual discharge head on the pump. The friction head increases as the velocity of discharge increases and decreases as the pipe diameter increases. It is directly proportional to the length of pipe line. Curvature in the

line, sleeve and ball joints in the pontoon line and gate valves develope a certain amount of friction head, but, for the average line of reasonable straightness, this is neglected and, in the determination of the value of the friction head, the pipe is regarded as straight. Hyraulic dredging is by no means an exact science, and the friction head in particular varies with the nature of the material dredged so that it would be inconsistent to attempt to evaluate such minor head losses as are caused by pipe fittings and moderate curvature.

The Table on Page 75 copied from the Morris Machine Works Catalogue, gives full data as to friction head, velocity and discharge for water flowing through pipes. Since the frictional resistance is greater for hydraulic dredgings or pumpings than for water, the values of the head in this table must be increased for dredging computations by an amount depending upon the nature of the material being dredged. By multiplying the friction values for water by 1.35, very good results are obtained for average hydraulic material. The increase varies from 0.1 to 0.5.

The key to the investigation of dredge pump performance is the relation between the total head and the peripheral velocity of the impeller or runner. From any discussion of the theory of the centrifugal pump, it can readily be determined that the peripheral speed is directly proportional to the square root of the total head, or if

P. V. = the peripheral velocity of the impeller
H = the total head
and C = a constant
then P. V. = $C\sqrt{H}$

The value of the constant, C, varies somewhat with the capacity, being higher for higher capacity; also with the ratio between the outside diameter of the runner and that of the throat opening, being higher for smaller diameter runners with the same throat opening; and also with the angle of slope of the vanes at the periphery, being

CAPACITY IN GALLONS PER MINUTE DISCHARGED AT VELOCITIES IN FEET PER SECOND, FROM 3 TO 15. ALSO FRICTION HEAD IN FEET PER 100 FEET LENGTH OF PIPE

Diam. Pipe	1-inch		2-inch		3-inch		4-inch		Diam. Pipe
Velocity	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Velocity
3	7.34	4.08	29.37	2.04	66.09	1.36	117.50	1.02	3
4	9.79	6.83	39.16	3.41	88.12	2.27	156.67	1.71	4
5	12.24	10.2	48.95	5.12	110.15	3.41	195.70	2.56	5
6	14.68	14.3	58.74	7.16	132.18	4.78	235.84	3.58	6
7	17.13	19.0	68.53	9.54	154.21	6.36	274.98	4.77	7
8	19.58	24.5	78.32	12.2	176.24	8.16	314.12	6.12	8
8½	20.80	27.4	83.23	13.7	187.25	9.15	333.75	6.86	8½
9	22.03	30.5	88.11	15.2	198.27	10.1	352.26	7.64	9
9½	23.25	33.8	93.00	16.9	209.24	11.2	371.90	8.46	9½
10	24.48	37.3	97.90	18.6	220.30	12.4	391.40	9.33	10
10½	25.70	40.9	102.80	20.4	231.31	13.6	411.05	10.2	10½
11	26.92	44.7	107.69	22.3	242.33	14.9	430.54	11.1	11
11½	28.15	48.7	112.58	24.3	253.34	16.2	450.20	12.1	11½
12	29.37	52.8	117.48	26.4	264.36	17.6	470.68	13.2	12
13	31.82	61.5	127.27	30.7	286.39	20.5	509.82	15.3	13
14	34.27	71.0	137.06	35.5	308.42	23.7	548.96	17.7	14
15	36.72	81.0	146.85	40.5	330.45	27.0	587.10	20.3	15

Diam. Pipe	5-inch		6-inch		7-inch		8-inch		Diam. Pipe
Velocity	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Velocity
3	183.63	.816	264.24	.68	359.79	.583	470.04	.510	3
4	244.84	1.36	352.32	1.13	479.72	.976	626.72	.854	4
5	306.05	2.05	440.40	1.70	599.65	1.46	783.40	1.28	5
6	367.26	2.86	528.48	2.38	719.58	2.05	940.08	1.79	6
7	428.47	3.81	616.56	3.18	839.51	2.72	1096.7	2.38	7
8	489.68	4.90	705.64	4.08	959.44	3.49	1253.4	3.06	8
8½	520.61	5.49	749.01	4.57	1019.4	3.92	1331.5	3.43	8½
9	550.89	6.11	793.72	5.09	1079.4	4.36	1410.1	3.82	9
9½	581.25	6.77	837.08	5.61	1139.4	4.83	1488.0	4.23	9½
10	612.10	7.46	881.80	6.21	1199.3	5.33	1566.8	4.66	10
10½	642.43	8.19	925.20	6.82	1259.3	5.84	1645.8	5.22	10½
11	673.31	8.95	969.88	7.45	1319.2	6.39	1723.5	5.59	11
11½	703.62	9.74	1013.3	8.11	1379.2	6.95	1801.5	6.08	11½
12	734.52	10.5	1057.9	8.80	1439.2	7.54	1880.2	6.60	12
13	795.73	12.3	1145.0	10.2	1559.1	8.79	2036.8	7.00	13
14	856.94	14.2	1233.1	11.8	1679.0	10.1	2193.5	8.87	14
15	918.15	16.2	1321.2	13.5	1799.0	11.6	2350.2	10.1	15

Diam. Pipe	9-inch		10-inch		12-inch		14-inch		Diam. Pipe
Velocity	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Velocity
3	594.78	.453	734.40	.408	1057.5	.347	1439.0	.291	3
4	793.04	.759	979.20	.683	1410.0	.581	1919.7	.488	4
5	991.30	1.13	1224.0	1.02	1762.6	.871	2399.4	.731	5
6	1189.5	1.59	1468.8	1.43	2115.1	1.21	2878.0	1.02	6
7	1388.8	2.12	1713.6	1.90	2467.6	1.62	3358.7	1.36	7
8	1586.0	2.72	1958.4	2.45	2820.1	2.08	3838.4	1.75	8
8½	1685.0	3.05	2080.8	2.74	2996.3	2.33	4078.3	1.96	8½
9	1784.3	3.40	2203.2	3.05	3172.7	2.60	4318.1	2.18	9
9½	1883.5	3.76	2325.6	3.38	3348.9	2.88	4558.0	2.42	9½
10	1982.6	4.14	2448.0	3.73	3525.2	3.17	4798.0	2.66	10
10½	2082.7	4.55	2570.8	4.09	3701.4	3.48	5037.7	2.92	10½
11	2181.9	4.97	2692.8	4.47	3877.7	3.80	5277.5	3.19	11
11½	2280.0	5.41	2815.2	4.87	4053.8	4.14	5517.4	3.48	11½
12	2279.1	5.87	2937.6	5.28	4230.2	4.49	5757.2	3.77	12
13	2577.4	6.84	3182.4	6.15	4582.8	5.23	6237.8	4.40	13
14	2776.6	7.88	3427.2	7.10	4935.4	6.03	6717.5	5.06	14
15	2974.9	9.00	3672.0	8.10	5287.8	6.89	7107.2	5.79	15

Capacity in Gallons per Minute Discharged—*Continued*

Diam. Pipe	15-inch		18-inch		20-inch		22-inch		Diam. Pipe
Velocity	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Velocity
3	1652.2	.272	2379.7	.227	2937	.204	3554.1	.185	3
4	2203.0	.455	3172.6	.379	3916	.342	4739.8	.310	4
5	2754.7	.682	3965.5	.569	4896	.512	5924.5	.465	5
6	3304.4	.955	4758.4	.795	5875	.717	7108.2	.651	6
7	3855.2	1.27	5552.3	1.06	6854	.954	8293.9	.866	7
8	4406.9	1.63	6345.2	1.36	7833	1.22	9478.6	1.11	8
8½	4688.1	1.82	6741.9	1.52	8323.6	1.37	10071	1.25	8½
9	4957.7	2.04	7138.1	1.70	8812	1.53	10663	1.39	9
9½	5232.1	2.25	7534.8	1.88	9302.6	1.69	11255	1.54	9½
10	5508.4	2.50	7931.0	2.07	9792	1.87	11848	1.69	10
10½	5783.4	2.73	8328.8	2.27	10281	2.05	12440	1.86	10½
11	6058.2	2.98	8724.9	2.48	10771	2.24	13033	2.03	11
11½	6334.6	3.25	9121.7	2.70	11258	2.43	13625	2.21	11½
12	6609.9	3.52	9517.8	2.93	11750	2.64	14217	2.40	12
13	7160.6	4.10	10310	3.42	12729	3.08	15402	2.79	13
14	7711.4	4.73	11104	3.93	13708	3.55	16587	3.22	14
15	8262	5.40	11897	4.50	14688	4.05	17772	3.68	15

Diam. Pipe	24-inch		26-inch		28-inch		30-inch		Diam. Pipe
Velocity	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Velocity
3	4230.3	.170	4964.2	.157	5757.2	.146	6609	.136	3
4	5640.0	.284	6619.0	.262	7676.2	.244	8812	.227	4
5	7050.8	.426	8274.7	.394	9596.3	.366	11015	.341	5
6	8460.6	.597	9929.5	.550	11514	.512	13218	.478	6
7	9870.3	.794	11583	.753	13434	.681	15421	.636	7
8	11280	1.01	13238	.940	15353	.875	17624	.816	8
8½	11985	1.14	14066	1.05	16316	.980	18725	.915	8½
9	12690	1.27	14893	1.17	17273	1.09	19827	1.01	9
9½	13395	1.40	15721	1.30	18231	1 21	20928	1.12	9½
10	14100	1.55	16548	1.43	19192	1.33	22030	1.24	10
10½	14805	1.70	17375	1.57	20150	1.46	23131	1.36	10½
11	15510	1.86	18202	1.72	21111	1.60	24233	1.49	11
11½	16215	2.03	19029	1.87	22069	1.74	25338	1.62	11½
12	16920	2.20	19857	2.03	23030	1.89	26436	1.76	12
13	18330	2.56	21511	2.36	24950	2.20	28639	2.05	13
14	19740	2.95	23166	2.73	26869	2.53	30842	2.37	14
15	21150	3.37	24824	3.11	28788	2.89	33045	2.70	15

Diam. Pipe	32-inch		36-inch		42-inch		48-inch		Diam. Pipe
Velocity	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Velocity
3	7519.7	.127	9518	.113	12954	.097	16921	.085	3
4	10026	.213	12690	.189	17272	.163	22561	.143	4
5	12532	.320	15863	.284	21590	.244	28201	.213	5
6	15039	.447	19036	.397	25908	.341	33841	.298	6
7	17546	.591	22208	.528	30226	.454	39482	.397	7
8	20052	.764	25381	.679	34544	.583	55122	.510	8
8½	21306	.857	26967	.760	36704	.653	47942	.571	8½
9	22559	.954	28554	.847	38863	.728	50762	.636	9
9½	23812	1.06	30140	.938	41022	.806	53582	.694	9½
10	25065	1.16	31726	1.03	43181	.888	56403	.778	10
10½	26319	1.28	33313	1.13	45340	.975	59223	.851	10½
11	27572	1.40	34899	1.16	47499	1.06	62043	.930	11
11½	28825	1.52	36485	1.35	49658	1.16	64863	1.00	11½
12	30379	1.65	38072	1.46	51817	1.26	67683	1.10	12
13	32585	1.92	41244	1.70	56135	1.46	73324	1.28	13
14	35092	2.21	44417	1.97	60453	1.69	78964	1.48	14
15	37598	2.53	47590	2.24	64771	1.93	84604	1.69	15

smaller for larger angles. The determination of the constant is purely a matter of judgment with the above for a guide, but for average practice a value of 435 may be used with very good results. Therefore, when H is in feet and P. V. in feet per minute.

$$\text{P. V.} = 435\sqrt{\text{H}} \qquad (1.)$$

From this important equation, the number of revolutions per minute necessary for an impeller to turn that it may

FIG. 32.—20 inch pump driven by 1000 h.p. triple expansion engine. (*Courtesy of Morris Machine Works.*)

develop a given head can be determined; or, having the R. P. M. and total head, the proper diameter of impeller can be selected; or, knowing the R. P. M. and the impeller diameter of any machine, the head of which it is capable can be found.

In this connection, it is well to remember that the diameter of the impeller, for efficient operation, should never be less than 2.3 times the size of the pump; e.g., a 20-inch pump requires a runner at least 46 inches in diameter.

Power.—The theoretical horse power developed by the pump is equal to the continued product of the discharge in gallons per minute by the weight of one gallon of water in pounds by the total head in feet divided by 33,000 foot pounds per minute, or if

Q = the discharge in gallons per minute
and H = the total head in feet, then

$$\text{Theoretical H. P.} = \frac{Q \times 8.33 \times H}{33{,}000}$$

or

$$\text{Theo. H. P.} = \frac{Q \times H}{3960} \qquad (2.)$$

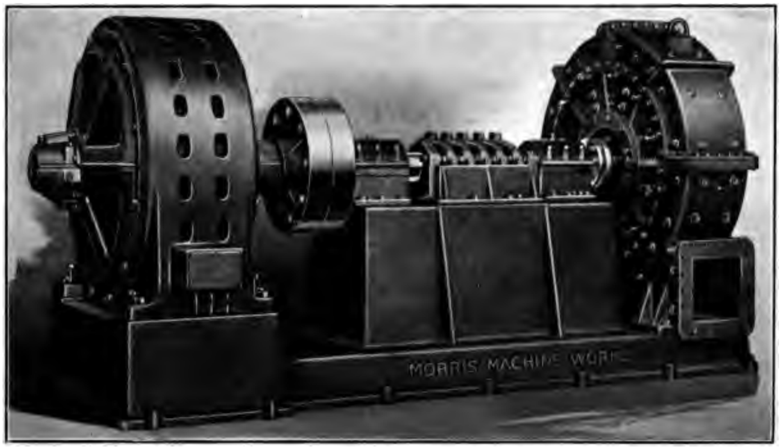


FIG. 33.—20 inch pump direct connected to 600 h.p. motor, one of four built for Panama.

The actual horse power required to drive the pump is about twice the above theoretical value since the efficiency of a dredge pump is generally about 50 per cent, or a trifle less.

For maximum economy of power, the velocity through the pipe should be no more than just enough to carry the material along because higher velocity means increased friction head and increased quantity, with both of which the horse power varies directly. For heavy material, such as coarse sand and gravel, however, the velocity

must be higher than for silt, mud and fine sand to prevent the settlement of the material in the pipe and the consequent choking.

Long pipe lines require a large impeller to give the high peripheral velocity necessary to overcome the great head. However, should the same impeller be used on short lines, the engine speed would be so retarded as to prevent the engine from delivering its maximum power. The smaller impeller in the short line allows greater engine speed, maximum power and, therefore, greater quantity of material pumped. It is obviously advantageous, therefore, that a dredge intended for miscellaneous work have several impellers of different diameters, increasing the size with lengthening pipe line.

Method of Design.—Let us assume that it is desired to design a hydraulic dredge capable of raising average hydraulic material 15 feet above the pump through 4000 feet of pipe line and at the same time be suitable for general all round work involvingalso short lines and low heads.

It is generally accepted that a 20 or 22 inch pump is the most advantageous for these conditions. We shall select the 20 inch. The next step is to choose the desired velocity of flow through the 4000 feet of line. Ordinarily the velocity should not be less than 12 feet per second, but as this length of pipe is the ultimate condition and as the assumption of a high velocity here would result in an excessively high velocity for short lines even with a smaller impeller in the pump, we will fix 10 ft. per second as the proper figure for 4000 feet of line and an elevation head of 15 feet. Entering the table, Page 76, we find that for 10 feet velocity in a 20 inch pipe, the friction head per 100 feet of pipe is 1.87 feet. But this value is for water and must be multiplied by 1.35 to obtain the head for dredgings, which is 2.52 feet, and the friction head for 4000 feet of pipe is 40 $\times$ 2.52 or 100.8 feet. The pump should be able to hold a vacuum of about 12 inches of mercury.

Therefore,

Elevation head.	=	15.0 ft.
Friction head.	=	100.8 ft.
Suction head 12 × 1.13	=	13.6 ft.
Total Head		129.4 ft.

or say 130 ft.

The peripheral velocity of impeller necessary to develop this head is found by formula (1) Page 77.

$$\text{P. V.} = 435\sqrt{130} = 4970. \text{ feet per minute}$$

bearing in mind that the constant 435 involves the use of the usual type of impeller as previously described. The engine speed for dredges of this size on long lines appears to be generally from about 200 to 225 revolutions per minute. Let us assume for our problem a value of 220 R.P.M. Then the required diameter of impeller is $\frac{4970}{220 \times 3.142}$ or 7.19 feet or 86 inches.

The water horse power for this condition is from formula (2) Page 78, $\frac{9800 \times 130}{3960} = 322$, and, for a pump efficiency of 50 per cent the engine brake horse power would be twice 322 or about 650.

Now let us investigate the same pump under a low head. Assume a short line, say 1200 feet and a low lift, 10 feet. Using the same impeller and engine speed as above, the developed head is again 130 feet, of which 13.6 feet is suction, 10 ft. elevation, and the balance, 106 ft. friction head. For a 1200 ft. line, the friction loss per 100 ft. of pipe is 8.83 ft. corresponding to a velocity of about 19.5 ft. per second, which is excessive. The remedy is either reduced engine speed or a smaller impeller or both. Suppose an impeller 78 in. in diameter be substituted for the 86 in. and driven at the same speed and under the same low head conditions as above.

$$\text{P.V.} = 6.5 \times 3.142 \times 220 = 4500$$

and the developed head $= \left(\frac{4500}{435}\right)^2 = 107$ ft. The friction

head = 107 − 24 = 83 ft. or 6.91 ft. per 100. For water, the equivalent head $= \frac{6.91}{1.35} = 5.12$, and the velocity is again excessive, approximating 17 ft. per second, requiring a shaft horse power of about $\frac{16{,}500 \times 107 \times 2}{3960} = 900$.

The high velocity may be reduced by increasing the size of the discharge pipe or by reducing the R.P.M. Still using the 78 inch impeller, but cutting the engine speed to 200 R.P.M. the total head developed is $\left(\frac{6.5 \times 3.142 \times 200}{435}\right)^2$ or 88 ft.; the friction head is 88 − 24 = 64 ft. or 5.33 ft. per 100 ft. of the 1200 ft. line. Dividing by 1.35 we enter the table with a value 3.95 and find that the corresponding velocity is almost 15 ft. per second and the discharge about 14,500 gallons per minute. The engine horse power required is $\frac{14{,}600 \times 88 \times 2}{3960}$ or about 650.

The foregoing leads us to the following conclusions:—that, for the problem stated, the solution appears to be a 20 in. pump with 20 in. suction and discharge, having at least two sizes of impeller, about 78 in. for short and 86 in. for long lines, driven by a triple expansion steam engine of about 800 horse power, turning over from 200 to 225 R.P.M. Although this is a greater horse power than theoretically required according to the above figures, it is recommended because of the necessarily uncertain nature of the factors involved and the desire for reserve power to take care of severe pumping conditions.

The Machinery.—The pump drive must be capable of variable speed and of running at different speeds for long periods of time because the load on the pump is variable due to the fluctuating suction head, the nature of the material and the varying length of pipe line. A steam engine meets this condition fully and is admirably adapted to the purpose. If the pump is driven electrically the motor must be designed for this varying load. A synchronous motor is, therefore, unsatisfactory. Although electrically

driven machines have been successfully operated, the usual drive is a triple expansion vertical condensing engine, directly connected to the pump and called the main engine. The 20 in. dredge NEW JERSEY, shown on Page 69, has cylinders 18 and 24 and 40 inches in diameter with a common stroke of 20 inches, 200 R.P.M., and developes 750 h.p. The 22 inch machine "TAMPA" pictured on Page 60, has cylinders 14 and 21½ and 36 inches, 18 inch stroke, 225 R.P.M. and 800 horse power. The boilers are variously Scotch, Heine or Almy water tube, and B. & W. with a working pressure of from 175 to 225 pounds.

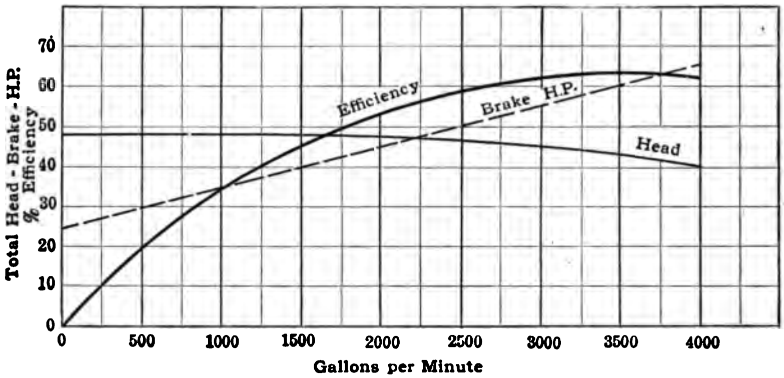


FIG. 34.—Characteristic curves—dredge pump. Constant speed. (*Courtesy the Morris Machine Works.*)

Between the pump and the main engine, a thrust bearing on the shaft is required because of the axial pull of the impeller. The shaft bearing at the impeller is kept clean by a water service.

The cutter engine will be about 12 × 12 double cylinder for a 20 in. machine and the winding engine about 8¼ × 12 double cylinder, driving at least 5 drums for swinging wires, spuds and ladder hoist, or more if the dredge be of the swinging ladder type with walking spuds and stern wire.

In addition to the above, there are the condenser and centrifugal circulating pump, the air pump, the generator set for electric lighting and the other auxiliaries.

Operation.—The leverman has full control of the manipulation of the dredge. The lever-room is located well forward and at such an elevation that the leverman can keep a watchful eye on the swinging of the machine or ladder, the ranges to which he is working, a tide gage, the behavior of the cutter engine and the condition of the floating pipe line. In the lever-room, are the vacuum, discharge-pressure and steam-pressure gauges, which guide the operator in the normal operation of the pump and feed. The vacuum in the suction pipe is greater when pumping solids than when water only is passing through, becoming maximum when the suction is choked. The discharge pressure falls off for chokes in the suction and rises for obstructions in the discharge pipe. The leverman learns to keep the gauge readings at that point at which the pump will carry the maxmum amount of material without choking. Both vacuum and pressure readings acquaint the operator of restricted suction, the former by rising and the latter by falling, but the vacuum gage is more sensitive than the pressure, responding more quickly to the abnormal condition. Through gratings in the floor of the lever-room, the operator keeps himself informed as to the amount of swinging wire left on the drums in the room below him. The depth of the cutterhead below the water surface is indicated by a sliding weight on the boom or by a dial in the lever-room, operated through reduction tackle.

Under the most favorable conditions, in mud and silt, hydraulic dredges may reach a maximum solid output of 25 to 30 per cent of the pumpings, but in average digging, the percentage will be more nearly 10 to possibly 15 and in heavy material with long lines it will fall as low as 5.

Booster or Relay Pumps.—When a discharge pipe line becomes so long as to reduce the output of the dredge below the economic minimum, material assistance may be rendered the dredge pump by placing in the shore line a second pump called a booster or relay pump. The dredge discharges directly into the suction of the booster, which then forces the pumpings through the remaining length of

line between itself and the fill. Thus the dredge pump is relieved of the length of line beyond the booster and is enabled to accelerate the pipe velocity and to increase the quantity of discharge. It is apparent that, for maximum efficiency of the combination, the booster must discharge an amount equal to that delivered to it by the dredge. If the booster receives more than it can handle, the output of the dredge is decreased by retarded velocity, although it may be greater than in the long line without the booster. If the booster is capable of a greater discharge than that delivered to it, it will draw air into its suction and pump the mixture. It is difficult to make the ordinary dredge shore pipe air tight. If the dredge discharge is sufficiently less than that of the booster, the load on the latter will

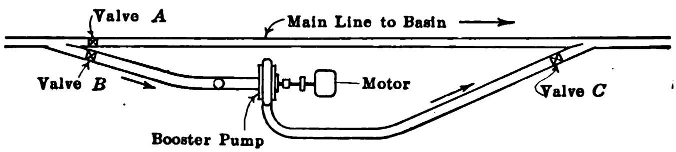


FIG. 35.—Typical booster installation.

be intermittent, i.e., the booster receives a column of pumpings and disposes of it so quickly that the continuity of the supply is broken, leaving a void between supply columns during which the impeller rumbles around in a mixture of air and water before receiving the next column, which is as quickly discharged. Consequently the discharge at the end of the pipe on the fill reveals a very appreciable pulsation. It is apparent, therefore, that there is one best place in the line at which to install a given booster, and the usual problem will be the determination of that point rather than to design or select a booster for a particular point, since neither are dredging operations so permanent nor boosters so plentiful as to afford frequent opportunities for the latter.

The solution of the problem again involves the question of peripheral speed of impellers. Knowing the diameter and R.P.M. of the dredge and booster impellers, select a

point in the line for trial. Compute the pipe velocity created by the dredge for the length of line from dredge to booster. Compute the pipe velocity created by the booster for the length of line beyond it not forgetting that this length will vary usually by the periodical addition of extra pipe sections. Reasonable variations in pipe length can be taken care of by varying the speed of the drives on either dredge or relay, or both. For large differences, a second impeller for the booster may be necessary. By a little manipulation the point in the line at which the relay must be located to insure equal pipe velocities of dredge and booster can be determined.

From the above, it is obvious that the booster drive must be capable of variable speed. If electrically driven, as most of them are, to facilitate transportation, installation and operation, the motor should be designed to run for long periods at various speeds without overheating. Synchronous motors are, therefore, wholly unsatisfactory for this purpose.

The pump is directly connected to the motor with a thrust bearing between the two. The latter need not be so heavy as that on the dredge since the water enters the pump normally without vacuum. It is desirable to have a flexible shaft coupling near the motor to provide for changes in alignment. The behavior of the pump should be carefully watched by means of vacuum and pressure gages on the suction and a pressure gage on the discharge. The vacuum gage should read zero for normal behavior. The load on the motor must also be noted by gauge. It is almost essential that there be a by-pass line around the booster so that it may be cut out of the line for repairs or other causes without interruption to the dredge pump, and that it may be given the load gradually, in starting, to prevent an overload on the motor. The by-pass is effected by two "Y" branches in the line, one beyond each end of the booster. The "Y" branch between the dredge and booster must have a gate or valve in each leg but that beyond need have a gate in the booster leg only. A typical installation is shown in Figure 35, page 84.

To throw the booster into the line, the procedure is as follows: Start the motor with valves *B* and *C* closed; have the dredge pump water only; leaving valve *A* open, open *C* partly then *B* about the same distance; open *B* wide; then *C* all the way; close *A*; have the dredge pump mud. The reasons are obvious. The minimum load on the motor occurs with the valve *C* closed, giving maximum head, zero discharge and therefore a minimum power requirement which is the desired starting condition. There is considerable danger, however, of blowing the line apart at *C* if pumping against that valve closed. Hence it is partially opened.

The installation should be housed, and it is essential that telephone communication or some system of signalling be established between dredge and booster so that the orders to stop, start, pump water and pump mud may be quickly conveyed.

Forward Feeding or Mississippi River Type

General Description.—The maintenance of low-water navigation in the shallow waters of alluvial rivers through the persistent and shifting sand-bar formations is a problem requiring special treatment. In the Mississippi River, these bars, during seasons of high water, assume extensive proportions, but as the river falls, they are cut out by the current erosion, and it is to assist and hasten this natural deepening tendency that the dredges are designed. To complicate matters, the usual dredging season, i.e., that portion of the year during which the state of low water exists; is only four months in length—from August 15 to December 15. (The river has a range in stage of upwards of 50 feet in places.) The amount of dredging to be done in any one season cannot be predicted, because of the impossibility of forecasting the stage or the rapidity of fluctuation. The only solution, therefore, appears to be simply that the dredges be available during the low-water season, to do whatever dredging may be required.

After repeated failures to make and maintain the depth necessary for low-stage navigation by means of current deflectors, water jets, stirring and scraping machines and other devices, the Mississippi River Commission, in 1892, built the 30 inch hydraulic dredge, ALPHA, for experimental purposes. The ALPHA proved so successful that eight additional machines were built by the Commission within the next decade. Various improvements and changes were made in the successive dredges, as experience dictated, until the type of to-day was developed and the Mississippi problem solved.

The typical Mississippi River Dredge differs from the radial feeding machine with spud anchorage, principally in:

1. *Greater capacity and lighter draft,* both of which features are necessitated by local conditions.

2. *The Method of Feeding.*—While some units of the Mississippi River plant are self propelling, being equipped with side paddle-wheels, many are pulled forward over the bar to be dredged by two cables extending from hauling engines on the forward deck to mooring piles driven in advance of the dredge. For holding the dredge in position while running lines or shifting the mooring piles, a single spud is set well forward.

3. *The Use of Water Jet Agitators.*—On the Mississippi the mechanical cutter has been largely replaced by the water-jet agitator. The suction head, which is at the bow of the dredge—as is the pump also—is flattened down to a depth of about 8 inches and flared horizontally to a considerable width varying from about 20 to 40 feet. Beneath the suction head is a pressure chamber with a series of nozzles, through which water is pumped under pressure, constituting the jet agitator, the province of which is to loosen the sand or other material for entrance into the suction.

4. *Smaller Maximum Depth Capable of being Made.* Mississippi River Dredges are generally equipped to lower their suctions to a depth not exceeding 20 feet, and the

practice, apparently, is to dig always as deep as the suction head will permit.

5. *Use of the Double Suction.*—Most of the dredges built by the Commission have a single dredge pump set vertically in the plane of the longitudinal axis of the hull, with a double suction leading into it on both the port and starboard side, and a single discharge pipe extending axially from the pump to the stern of the dredge, thence to the pontoon line. Each suction is, roughly, 24 inches in diameter, and the discharge pipe from 32 to 36 inches. Incidentally, the balanced suction obviates the necessity for a thrust bearing.

As in the other river types, the upper deck contains quarters for the captain and crew, numbering generally from 45 to 50 men.

The bars to be dredged form as a rule diagonally across the river at the point of change in the direction of curvature of the current, so that they lie between two pools of relatively deep water, located at the outer bank of two successive bends in the river. The axis of the dredged cut should coincide with the direction of the current, using a sufficient length of pontoon line to discharge into the deep water below the bar. Successive parallel cuts yield the desired channel width.

More detailed information regarding the Mississippi River Dredges and the performance tests made by the Commission is contained in a paper by F. B. Maltby, M. Am., Soc. C. E., published in Vol. LIV., of the *Transactions.*

CHAPTER VII

HYDRAULIC DREDGES OF THE SEA-GOING HOPPER TYPE

Historical.—In the improvement and maintenance of important harbors and entrance channels, involving the dredging of ocean bars in exposed locations, it was early realized by the U. S. Government through the Corps of Army Engineers, in charge of all such work, that the most economic method of attack was by government-built and operated dredges of large capacity, capable of removing great quantities of material within a reasonable time at low cost. This conclusion was reached after repeated failures of dipper and grapple dredges economically to cope with the situation. With such types one of two equally undesirable results was experienced: either the dredges and the numerous items of appurtenant floating plant were rapidly destroyed by the continual pounding against each other, or else the work proved slow and expensive because of the large precentage of lost time waiting for calm weather. Since larger and more suitable dredges were not to be had of the contractors, the Government, apparently adopted the only alternative, and since 1890 more than twenty seagoing suction dredges have been built by them.

The use of this type of dredge in the United States dates as far back as 1855. Quoting from Major J. C. Sanford's very excellent paper on "Dredging Ocean Bars," printed in Vol. LIV. Transactions Am. Soc. C. E., "The earliest dredge of this type used in the United States was, it is believed, the GEN. MOULTRIE, used in 1855, at Charleston, S. C. . . . This dredge is stated to have been a moderate sized commercial steamboat, converted into a dredge by the addition of centrifugal dredging pumps with necessary

piping, etc., and with bins constructed in the hold. Her drags, or suction heads, were probably somewhat similar to those now in use. . . . From 25 cents to $1.00 per cu. yd. for material dredged, according to locality and amount of work, was still (previous to 1890) considered a fair price for dredging on ocean bars; and on account of the great cost of dredging, the plan of deepening these bars by scour produced by jetties was regarded as the only practicable one."

FIG. 36.—The Comstock. *(Courtesy the Bucyrus Co.)*

However, after the conclusion, in 1891, of six years of dredging, by contract, to deepen the entrance channel to New York Harbor, "the cost of maintaining the dredged channel to full width and depth has been found to be very moderate."

The first suction hopper dredge built by the Government was the CHARLESTON, in 1890, having one 15 inch pump and a bin capacity of 340 cu. yds. Between 1890 and 1900,

three more were built, the performance of which effected such a reduction in the cost of dredging ocean bars as to question the economy of constructing the costly jetty for the purpose of deepening these channels. Since 1900, the Government has built a goodly fleet of these machines, probably the most intensive construction period being from 1901 to 1904, during which the total number constructed and under construction was 14. Two such dredges, the CARIBBEAN and CULEBRA, built in 1907 by the Maryland Steel Company, of Baltimore, Md., were used in the construction of the Panama Canal.

General Description.—The sea-going hydraulic dredge is a self propelled vessel with moulded hull, containing one or two main pumping plants, and with hoppers for receiving and transporting the material. In addition to the apparatus required solely for the dredging operation, it is equipped with all the machinery and appliances necessary to ocean navigation.

The hull is generally steel with a hopper capacity of from 2000 to 3000 cubic yards, and from 200 to 300 feet long. Some types have but one dredge pump and one suction pipe operating through a central well. The majority, however, have two pumps and two suctions, as experience has proven the advantage of the dual installation. The suction pipe is hinged at the pump, and raised and lowered by tackle. The joint must be flexible to allow a certain amount of hull motion without disrupting the pipe. The suction end, resting on the bottom is provided with a scraper or shoe to feed the pump. In operation, the dredge travels forward at a speed of about 6 knots, with the suction head or shoe dragging on the mud. The material is distributed evenly in the bins through pipes and distributing chutes. The large amount of accompanying water is drained off by overflow through the sides, or over raised coamings. When loaded, the dredge steams to the dumping ground and discharges the hoppers through gates on the bottom, which are operated by a vertical engine-driven worm or similar arrangement. Some dredges are

equipped to empty their bins by means of their dredge pumps. American practice tends to two large bins, one forward and one aft of the machinery space.

There are two details which merit especial attention, as a proper consideration of them is so necessary to the success of the unit. They are the drag—or scraper or shoe—and the flexible member of the suction for the purpose of accommodation to the pitching and rolling of the steamer. Of the former, many types have been used with varying success in different materials. No one design can be accepted as a standard for all conditions The latter usually consists of a section of rubber pipe about 10 feet long, inserted in the suction near the elbow.

A feature of the later suction hopper dredges is the introduction of overflows at different elevations in the hoppers, in order to reduce the load draft when working in shallow water. Although the use of the lower overflow necessarily effects a reduction in bin capacity, yet it is regarded as a permanent improvement, increasing the dredge's scope and adaptability.

Advantages of the Type—Mr. Sydney B. Williamson, Chief Engineer, Pacific Division, Panama Canal, writes:

> "This type of dredge has proven decidely the most economical for the work of improving and maintaining the harbors and channels of our coast, and the superiority is largely due to its being self-contained, self-propelling and possessing the ability to operate without anchorage."

While the machine is particularly adapted to ocean bar dredging, which is the work for which it was originally designed, it presents certain advantages for maintenance work in rivers and sheltered harbors. Because it excavates the shoal progressively from the top downward, instead of from the end, it is economical of operation in shallow cutting and, moreover, cooperates with the deepening tendencies of current scour. Requiring no anchorage, it offers no obstruction to navigation.

On the other hand, it is open to criticism in two particulars, viz., the discontinuity of dredging operation due to frequent trips to the dump, and, secondly, the large

proportion of unremunerative pumping because of the material carried away in suspension in the hopper effluent, which, of course, is much more true of alluvial silt than of material of greater specific gravity. The U. S. Dredge DELAWARE, operating on Duck Creek flats on the Delaware River, in 1908, found that it was impossible to fill the bins with solid material, owing to its very soft nature, and the desired results were accomplished by using the bins on the flood tide only, pumping directly overboard on the ebb tide so that the liquid material was carried by the current to deep water in the bay. This plan of operation continues in use to-day and is called the "agitation" method.

TYPICAL EXAMPLES	DELAWARE	CULEBRA
When built	1906	1907
Length overall	315′	288′
Beam (moulded)	52′	47½
Depth (moulded)	22½′	25
Bin capacity—cu. yds	3000	2300
No. of pumps	2	2
Size of pumps	20″	20″

PART II

DREDGING

CHAPTER VIII

OBJECTS AND PHASES OF THE SUBJECT

Our first thought as to the "why" of Dredging is the creation of water depths in excess of the natural, nor have our mental processes erred in the spontaneous answer. Yet there are several other important purposes of the art and many reasons for increasing the depth of water. The *Objects of Dredging* may be included broadly under four headings:

1. The creation of water depths in excess of the natural.
2. The acquisition of subaqueous material for use as fill.
3. The construction of dikes and levees.
4. The acquisition of subaqueous material for its commercial value.

The first may be desired for the navigation of ships; for harbors; for the control of rivers and other water-ways; for construction purposes in connection with piers, wharves, docks, shipways, dams and subaqueous foundations generally; and for drainage and irrigation.

The second refers to the utilization of the "dredgings," or dredged material, for land reclamation; for the rehabilitation of swamp-lands and marshes; for filling litoral structures; and for "making bottom," i.e., the deposition of heavy material upon a soft mud bottom to displace and compact the mud with the idea of increasing the bearing power and lateral stability of the original yielding material.

The third heading covers the use of the dredge as the sole or appurtenant agent in the construction of dikes

for river control and for impounding basins and land reclamations.

The fourth comprises the dredging of sand, gravel and clay for building purposes; of phosphate rock for fertilizer; of gold and other metals; and even of subaqueous coal in some localities.

Finally, a dredging operation may have a dual function, such as making depth and building up a fill at the same time.

It is beyond the scope of this book to treat of dredging in all its branches as summarized above but rather will the discussion apply to excavation for depth and the useful disposal of the dredged material in making fills.

A dredging project of reasonable magnitude will usually have three successive phases or stages and we will present the subject so divided, believing that both the readers' grasp and our exposition will be facilitated thereby. They are first, the *Preliminary Engineering*, by which the site is explored and the work laid out; second, the *Preliminary Construction* of appurtenant structures that must be built before actual dredging can be commenced, such as dikes, sluiceways and pipe lines; and third, the *Operation*, when, the stage set and the plant assembled and working upon the predetermined program, the job becomes, by natural growth, a purely operating problem.

CHAPTER IX

PRELIMINARY ENGINEERING

Exploration of Site.—The initial step in any proposed dredging operation is the examination of the physical properties of the site of the work, and often of the adjacent terrain as well, for the determination of the location and outline of the area to be dredged, the quantity and nature of the material to be removed to meet the requirements, and the selection of impounding basin sites for the disposal of the dredgings. This is accomplished by a survey, partly topographic as well as hydrographic, and by borings.

As a basis for the survey, a set of coordinates is established with reference to a convenient origin, usually tied in to the War Department Engineers' stations, and a base line and triangulation system are laid off. From the main triangulation stations, secondary stations are located at points from which soundings may be located conveniently by instrument intersection. Sounding parties, each consisting of a chief of party, two instrument men, a leadsman, a recorder and a boatman, are then sent out. A gauge, to measure the varying elevation of the water surface, is set with its zero at the datum used, and a gauge-reader observes and records the readings thereon at stated time intervals. The same results may be obtained automatically by the use of an instrument called a hydrochronograph, which is, in principle, a cylinder rotated by a clock and wrapped with cross section paper, upon which a stylus, rising and falling with the water, traces the curve of varying surface elevation. If in tidal waters, the gauge will be a tide-gauge with its zero at mean low water, and, since all soundings are referred to the datum, the gauge record must be made whenever soundings are being taken. Ranges are established indicating the lines of soundings.

As the boat containing the leadsman, recorder, boatman and usually the chief of party, traverses a range, the two transitmen on shore, set up on known stations, locate it by simultaneous angle readings upon signal from the boat. It is customaty to signal at a constant time interval, perhaps of one minute. The leadsman heaves the lead constantly, calling off the depths to the recorder, while the boatman keeps the craft on range and varies his speed with the depth of water so that the soundings may be a more uniform distance apart. That sounding which is taken just as the signal is given the transitmen to read, is termed "on the cut-off" and is so marked in the book. The draughtsman in the office first plots these "cut-offs" and then divides the straight line connecting each pair into equal parts for the intermediate soundings. The soundings may be obtained as close as desired by regulating the speed of the boat and the distance between ranges. The engineer in charge should use some judgment as to the proper number of soundings commensurate with the given requirements. When the entire area has been covered, the final sounding sheet is prepared, showing also the coordinates and contours.

As the direction and velocity of flow will very often have an important bearing upon the proper location of a channel, particularly as to the maintenance thereof, it may be neccessary to obtain some data in this regard. Taking "current-drift," as it is called, is accomplished as follows: A number of floats are made, deep enough to represent the average flow and almost entirely submerged to reduce the wind influence to a minimum. They are released at intervals in the cross section of the water way and permitted to take their own courses. The chief of party, in a motor boat, runs from float to float, signalling by flag to two transitmen on shore, who read simultaneously upon signal. Each instrument man also records the time of each reading, their watches having been set in agreement. The angular intersections are plotted and the time of each shown, so that the broken line connecting successive

positions of each float shows the path taken and the distance travelled in a stated time. The current-drift tracing and the sounding chart should be drawn to the same scale that they may be superimposed to determine the relation between depth and flow.

The character of the bottom strata is investigated either by *probings* or *borings*. By probing is meant simply "feeling out" the bottom with a pointed rod or pipe, which is thrust into and worked down through the soil by two or three men or by a maul or monkey. The depth of penetration is an indication of the hardness of the bottom, and an experienced man can tell, within limits, the nature of the strata by the feel of the probe as he works it. The results obtained are neither so complete nor so reliable as the information yielded by borings, and, unless taken by a first-class man, may even be misleading. The only features of probing that can be cited as recommendations for its use are inexpensiveness and convenience, with the reservation that the time and money saved may easily prove a false economy. For purposes other than the determination of the nature of the material to be dredged, however, such as locating the contour of the underlying bed rock by driving a heavy probe with a power driven drop hammer of light proportions, probing may give fairly accurate results, and, in such employment, the above criticism is not entirely applicable.

Borings differ from probings principally in that, with the former, samples of the material are obtained. There are two principal kinds of borings, *wash* and *core* borings, although a combination of the two methods will often effect an economy. Various makeshifts have been tried with more or less success for bringing samples of the bottom material to the surface for examination, such as thrusting an open pipe into the soil and removing the contents thereof after raising it clear of the water and again by the use of a wood-auger. The true boring, however, whether wash or core, implies the use of a casing, consisting of sections of heavy pipe about 3 inches in diameter. In the wash

boring the active instrument consists of a hollow drill rod, a tube or pipe of smaller diameter, having at its lower end a chopping bit with an X-shaped chisel point and with openings for a water jet. The drill rod is worked down inside the casing by rotating it, or by raising and dropping it through short heights, or by the two motions combined. At the same time, water is forced down the hollow drill rod by a force pump, and, escaping through the jet holes in the bitt, carries upward the loose material in the annular space between the rod and casing. Simultaneously, the casing is also worked down by rotation or by driving. The overflow from the top of the casing is caught in a bucket and allowed to settle, and the samples therefrom are preserved in bottles duly labelled. The apparatus is handled by a derrick frame and hoist mounted on a scow or by a pile driver.

While the term, "core boring," is generally applied to the use of core drills with diamond bitts or chilled steel or toothed cutters such as are used in testing rock strata, the drill being sunk by rapid rotation and raised at intervals for the removal of the core contained within it, core specimens may be obtained in connection with the use of the wash-boring apparatus described above and will generally suffice for dredging data, obviating the use of the more expensive equipment. This is done by substituting for the drill rod a short piece of brass pipe which is pressed into the bottom within the casing and lifted out for examination, or, in hard material, a saw-tooth, tubular bit may be used. The operation is performed in the dry and procures core samples of the material in its natural condition. The results of a wash boring are possible of misinterpretation due to the fact that the samples, having been jetted and churned, are not indicative of the true stratum relation and due also to the tendency of the jet to wash up only the finer material. It is advisable therefore to obtain dry core samples whenever feasible.

Estimating the Quantities.—The engineer is now in shape to locate definitely the area to be dredged, to esti-

mate the yardage to be removed, to choose the type of plant and method of disposal of the dredgings, to approximate the cost and finally to let the contract for the work.

The location of the area to be dredged, if not definitely fixed by local conditions, may involve the considerations of sedimentation, scour, bank maintenance, dikes or other factors of waterway control, which will be discussed more fully in a later chapter.

The quantity of material to be removed may be computed in several ways. First and most common is the method of vertical *cross sections* at regular intervals, from which the volume is obtained by average end areas or by the prismoidal formula. The second is the "*planimeter*" method. Each contour is traversed by the planimeter to find the included area, resulting in a series of areas of equidistant horizontal planes from which the volume follows as above. A third method, which might be termed the "*Unit*" scheme, divides the area into a number of squares of convenient size by ruling the plan with horizontal and vertical lines, uniformly spaced. From the average depth of cut in each square, the volume of dredging therein is computed and noted on the drawing. The first method is best adapted to long, narrow areas such as channels, canals, docks, etc., and the second and third to large polygonal areas.

To simplify the arithmetic involved, the following arrangements are useful. In the calculation of the volume by the method of average end areas, let A_1, A_2, A_3, . . . A_n represent the areas of successive cross sections, D the constant distance between sections, and V, the desired volume. Then

$$V = \left(\frac{A_1 + A_2}{2}\right) D + \left(\frac{A_2 + A_3}{2}\right) D + \left(\frac{A_3 + A_4}{2}\right) D + \dots \left(\frac{A_{n-1} + A_n}{2}\right) D$$

$$= \frac{D}{2} (A_1 + 2\,A_2 + 2A_3 + 2A_4 + \dots 2A_{n-1} + A_n)$$

$$= \frac{D}{2} [A_1 + A_n + 2\,(A_2 + A_3 + A_4 + \dots A_{n-1})]$$

Thus, having listed the areas of all the sections, add the first and last to twice the sum of the others and multiply the grand total by one-half the common distance between sections. The same principle is applicable to the determination of the areas of the sections, substituting ordinates for areas.

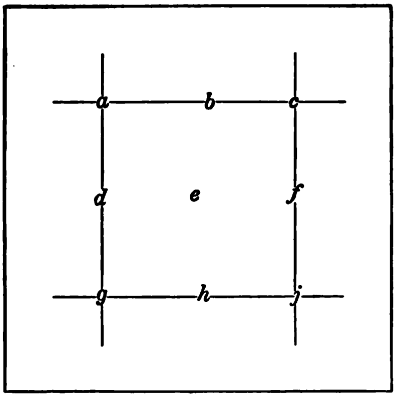


FIG. 37.—The unit method.

For volume computation by the prismoidal formula, a set of multipliers is used analogous to Simpson's multipliers for finding ship displacements. Using the same notation as above:

The volume of the prism A_1 to $A_3 = \frac{D}{3}(A_1 + 4A_2 + A_3)$

" " " " " A_3 to $A_5 = \frac{D}{3}(A_3 + 4A_4 + A_5)$

and $V = \frac{D}{3}(A_1 + 4A_2 + 2A_3 + 4A_4 + 2A_5 + \ldots A_n)$

The multipliers, therefore, are 1 for A_1, 4 for A_2, 2 for A_3, etc.

In computing the average depth in each square of the third, or *unit* method, the weighted mean must be determined. Assuming that the soundings are sufficiently close to fix 9 depths in each square, whether directly or by interpolation, as shown in Fig. 37, page 102, one in each

corner, one in the center of each ide and one in the middle, the average depth of water for the area of the square will be

$$\frac{A + C + G + J + 2(A + F + H + D) + 4E}{16}$$

The volume is reduced to cubic yards, the unit of measure in dredging.

The question of the degree of side slope that the sides of a dredged cut will assume is important and will have a considerable effect upon the estimated quantity of material to be removed. It is essential that the engineer approximate the ultimate inclination, even though he specify a minimum slope as the limit of pay quantities. Correct estimates are necessary to the fulfillment of schedules. Yet it is impossible to classify bottom materials upon the basis of amount of slope, since the combination of the controlling factors, nature and stratum relation of the materials, depth of cut and current influence, is never the same. It is advisable to supplement his judgment based upon the results of the borings by the knowledge of experience and by available local data. If the problem permits a generality, it may be said that, ordinarily, the side slope of dredged river channels will vary from 1 on 3 to 1 on 5 (excepting in rock excavations), and in docks, where the piling offers some support to the material, from 1 on 2 to 1 on 4. River silt, however, is often so semi-fluid in character as to assume a slope approaching 1 on ∞.

The actual quantity of material in place between the original bottom surface and the specified depth to be dredged is modified by two important factors; *overdepth dredging* and the *ratio between scow and place measurement*, the first being applicable to all dredging and the second to scowed material only. It is manifestly impossible for a dredge to excavate precisely to the plane desired. The dredged bottom will be more or less irregular no matter what the type of machine used, but more particularly with the use of grapples, of which, from the very nature of their mode of removal, it must be expected that the bottom will be

uneven and pitted to a degree depending upon the kind of material and the skill of the operator. For this reason, it is customary to specify a certain overdepth allowance, or, in other words, the adoption of a second plane, a short distance below the specified depth, with the understanding that the yardage unavoidably removed from between the two shall be included in the pay quantities. Thus, no penalty is exacted of the dredge for reasonable overdepth dredging, only such material as is excavated from below the overdepth plane being deducted from the total yardage credited to the machine. In the language of the U. S. Engineer Office, Washington, D. C., in specifications for dredging the Potomac and Rappahannock Rivers, 1917,

"To cover mechanical inaccuracies of dredging processes, material actually removed to a depth of not more than 1 foot below the required depth will be estimated and paid for at full contract price; to secure stable banks for the dredged cut, material which is actually removed on order of the contracting officer in quantities sufficient to make side slopes not flatter than one (1) on three (3), whether dredged *in situ* or after having fallen into the cut, will be estimated and paid for. The allowance for overdepth on the specified slopes will be the same as in the channel and will be measured vertically. Material taken from beyond the limits above described will be deducted from the estimates as *excessive overdepth dredging* and will not be paid for."

For grapple and dipper dredges, the usual overdepth allowance is two (2) feet, and for ladder and hydraulic machines, one (1) foot. In estimating the yardage to be removed, it is good practice to assume that all the allowed overdepth dredging will be removed, or, in other words, to include in the figure representing the total quantity to be dredged all the material lying above the allowed overdepth plane. Conservatism advises full rather than scant estimates, since upon them are based the appropriations and the schedules.

It is a well known fact that dredged material occupies more space in the scows than "in place" in the original bottom, but it is often a moot question as to the amount of expansion for any given material. Frequently, the necessity arises for converting place into scow measure-

ment and vice versa. Such of his place quantities as are to be scowed, the engineer increases by a certain percentage to arrive at the total quantity which will result from the number of scows loaded and the capacity of each scow, determined from the inside dimensions of the pockets. Material that is bucket dredged into scows is nearly always paid for by the cubic yard scow measure, but, whether the basis of compensation be scow or place measurement, occasions are prone to arise for the conversion of one to the other, even in the pay quantities and, for that reason, the relation between them is often fixed by the specifications.

Omitting rock, the percentage of increase over place quantities will vary from 5 to 25 per cent, depending upon the nature of the material. Since the expansion is due to the presence of voids in the contents of the scow in consequence of the breaking or cutting up of the monolithic mass of the original bottom, that material of which the separate bucket loads most nearly retain their shapes as dug will show the greatest volumetric increase. Such materials are blue clay and stiff mud and their percentage of increase should be taken as about 25 per cent. Going to the other extreme, those dredgings which are almost semi-fluid in character, such as river silt and find sand, and tend to run together in the pocket, with a resultant solidity more nearly approaching that of their original "in situ" condition, are increased in volume in the scows only about 5 per cent. Between these two limits, 5 and 25 per cent, other materials and combinations of materials will range according to their "body" or "cohesive stamina." For instance, the proper figure for a fairly heavy equal part mixture of sand and mud appears to be about 16⅔ per cent, or one-sixth. In the majority of dredging operations, other than those involving the removal of loose, rotten and bed rock, the quantity of material measured in place must be increased by from 15 to 25 per cent, to obtain the number of cubic yards scow measurement of the same material. Again quoting the U. S. Engineer Office, Washington, D. C.

from specifications for dredging in the Potomac and Rappahannock Rivers, 1917,

"When necessary for any cause to convert scow measurement into place measurement or the reverse, 100 cubic yards of the former will be taken as the equivalent of 80 cubic yards of the latter."

Here the material was defined as "freshet deposit . . . composed of sand and mud."

Deck loads of stone or rock are measured either by cross sectioning the pile or by displacement calculations from readings of the light and load draughts of the lighter upon glass tubes set in the four corners of the hold.

If the object of the dredging is the creation of a depth sufficient for the flotation of large steamships, there are several pertinent factors to be considered in the determination of that depth. The question is how much deeper than the load draft of the vessel at rest must the dredging be carried. In berths, adjacent to piers and wharves, obviously it is necessary merely that there be sufficient water to float the loaded vessel at times of extreme low water. It is often advisable, however, particularly where the bottom material is of a hard resistant nature and prone to irregularity, that an additional foot or two be provided as a factor of safety, but where the material is so soft and free of obstruction as to permit a reasonable "nesting" of the vessel to it without injury, this may not be necessary. The increasing tendency to ships of small bilge radius and dead rise, culminating in the fabricated ships of almost rectangular midships section requires that the dredged depth of the slip be practically as great immediately adjacent to the pier or wharf structure as elsewhere.

In ship channels traversed by large steamships under full speed, another factor must be considered, viz. the increased draft of the vessel due to her motion. This so-called "squatting" of moving vessels has been thoroughly investigated by instrumental observation from the shore, the results of which prove conclusively that the amount of "squatting" is of such magnitude as to require consideration. In many instances, the slight grounding of

moving vessels in the channels of New York Harbor where their draft at the pier was less than the presumed channel depth has been shown to be due to this squatting action instead of to the presence of shoals as at first thought. The study of the problem has lead to the following conclusions: that the "squatting" is apparently greater in shoal water than in deep, or in other words that the amount of "squat" is an inverse function of the depth of water below the keel; that it is greater at high speeds, or that its amount is some direct function of the speed; that, in the majority of cases, it is greater aft than forward, more particularly at high speed in shoal water; and that it probably varies with the lines of the hull. A "squat" of as much as four feet has been observed upon a large steamship traveling at high speed in shoal, calm water, and it has been shown, with little fear of contradiction, that, under the conditions most favorable to a great amount of "squat," large ships may require at least four feet more depth in the channel than indicated by their drafts at the pier. The "squatting" aft may be attributed to the hollow under the ship's stern, but it is not easy to perceive why the ship should "squat" at the bow.

Choice of Plant and Method of Disposal of Dredgings.—The question of the kind of plant best adapted to a particular piece of work is of the utmost importance and one in which a mistake may entail heavy loss in time and money. Whether the decision is the responsibility of the engineer or is left to the bidding contractors, it should be given due consideration by men of ripe experience. It is, of course, intimately related to the problem of the disposal of the dredgings, and must be discussed in conjunction therewith. The factors involved are as follows:

(*a*) Nature of the soil

(*b*) Proximity of a free dump

(*c*) Cost, proximity and accessibility of impounding basins, and the enhanced value of impounding basin property,

(*d*) Kind of plant available and the relative efficiency of units of the same type,

(e) Space limitations and interference with construction and traffic,
(f) Depth limitations,
(g) Time limitations,

Let us discuss them in the order named.

(a) The first leads to a comparison of the various types of dredge as to their relative merit in different soils. American and European engineers differ in their preference of dredge types. The ladder dredge enjoys considerable popularity abroad, while in this country the grab and dipper are much more extensively used. It is interesting to note the foreign and local expressions of opinion on the subject. Brysson Cunningham, an Englishman, in his "Dock Engineering," while admitting that the ladder "dredger" is not economical of power because of the inordinately high lift necessary to feed the chutes, nevertheless strongly commends it, writing that it is the only machine that can satisfactorily dig rock and is excellent in excavating stiff clay. He disposes of the dipper by the simple statement that "The Dipper Dredge is almost exclusively an American type," and of the grapple, writes as follows:—"The grab is an excellent tool and invaluable in confined situations, but it is scarcely suitable for general adoption in works on a large scale. It is not an economical instrument for the removal of stiff clay; its best performances are in regard to mud and soft earth. It cannot be counted upon to work with the same regularity and evenness as the ladder dredger; in fact, its tendency is to pit the surface of the ground with a series of hollows and depressions. But, in spite of these drawbacks, it has demonstrated its ability to such an extent that it is looked upon as an essential accompaniment of most dock and harbor undertakings." Even this may be regarded as quite a concession, when we remember that the usual English grab is simply one or two revolving cranes mounted upon a scow.

Prelini (American) in his "Dredges and Dredging," expresses American feeling in a nut-shell in the statement, "Dippers are an American product, and the marvel is that they do not attain wider recognition abroad in lieu of the *expensive ladder* dredges."

Fowler (American) in his "Practical Treatise on Subaqueous Foundations," says, referring to dippers,

"Such dredges are more simple in construction than elevator (ladder) dredges . . . . and are consequently easier and cheaper to keep in repair," and again, that many dippers have "sufficient power to dig hardpan, boulders and very soft shale rock," and yet again: "The ladder dredge, being so much more expensive to operate and keep in repair than clam-shell or dipper machines, is seldom used in the United States."

On the other hand, some engineers have criticised the American for his disregard of the advantages and efficiency of the ladder type, and have excused this shortcoming by the explanation that, in the development of this new country, dredging operations were secondary to larger and more important improvements, and, consequently, the small appropriations and the dearth of available funds resulted in the construction of small dredges of the cheapest possible type, and that, later, when dredging operations assumed larger proportions, the manufacturers built the more powerful machines along the lines of the earlier plant. Recently, however, the development of the ladder dredge has been fairly rapid, both in the gold mining industry of the western States and in the excavation of commercial sand and gravel in the east. Furthermore, the small French elevator machines, rebuilt and operated by the United States Government on the Panama Canal, excited favorable comment by their good work there. It would appear, therefore, that the criticism of dredging bigotry may justly be applied to both Europe and America; to Europe for her failure to recognize the merits of the dipper and, to a less degree of the grapple, and to America, for our obstinacy in refusing to consider the advantages of the elevator dredge. Undoubtedly, there are specific purposes and peculiar conditions for which each type is best adapted, and the earlier the recognition of this fact, the better for the dredging world.

Hydraulic machines are used extensively both here and abroad. Although first employed in France in 1867, they

have reached a high state of development in this country, and Fowler even goes so far as to claim that "The suction dredge is essentially an American tool." It is a particularly efficient instrument in that it not only dredges the material but also delivers it to the place and at the elevation desired with one operation. The cost of the dredge per capacity is less than that of other machines and, moreover, it is practically impossible to equal in any other type the enormous capacity of some hydraulic dredges in service. While it can be used in all classes of material short of solid rock, it is most efficient in handling homogeneous material that is not excessively hard, such as silt, mud, sand, clay and gravel, reasonably free of obstructions. Mud and fine sand are regarded as the best hydraulic materials. The pump can handle a greater percentage of solids when working in clay, but difficulty is experienced in agitating and cutting it in sufficient quantity to maintain the feed at the maximum capacity. The length of pipe line, as a controlling factor in dredging economy, varies with the nature of the pumpings. For heavy material, such as coarse sand, gravel and clay, the maximum economic length of line is less than for light materials easily carried in suspension, such as mud and fine sand. The greater tendency of the heavier pumpings toward rapid deposit, and the consequent decrease in the percentage of solid matter handled, coupled with increased pipe friction, causes outputs on long lines smaller than for the light material.

The grapple dredge is at its best in mud and stiff mud. Swinging a soft-digging bucket of large capacity and fitted with side-boards, it can maintain an output in such material in excess of dippers and ladders of equal expense. In harder material, however, as sand, gravel and clay, the hard-digging bucket of smaller size must be substituted, and moreover, the weight of the bucket, decreased by the lifting tendency of the closing wire is often insufficient to obtain the penetration necessary to obtain a full load. In other words, the closing bucket scrapes over the resistant bottom making a shallow bite and only partially filling

itself (See Chapter II). In soils of this kind, the dipper and the ladder will give better results than the grapple. The dipper is particularly well adapted to hard digging and to the removal of material containing a large amount of obstructions. It can readily handle stone and boulders and even soft rock. The grapple may be equipped to dredge stone and boulders by the use of a special open-tined stone grapple in place of the usual clam-shell bucket, but the dipper is preferable. In fact, when the material, whether the bulk be soft or compact, is full of obstruction such as stone, boulders, snags, piling or subaqueous structures, the dipper is the most efficient machine in use, but in soft, homogeneous material, the grapple is better. Especially is the pin-up dipper ill suited to soft digging, because such soil offers insufficient resistance to the penetration of the spuds, upon which the machine depends in the pinned-up condition. In clay or in hard sandy soils, the efficiency of the grab bucket may be somewhat increased by the addition of teeth or tines to its cutting edges, but the American tendency is rather to depend upon the great weight of the bucket. The orange peel bucket is seldom used on large operations but is often employed on small grapples in casting over work and in construction work where there is more or less loose rock or obstruction to pick up, or in the interior of cofferdams and caissons. A consideration appurtenant to the use of bucket dredges working in clay is the difficulty often experienced in dumping the scows. The clay becomes compacted in the pockets into a sticky mass arched across the door openings and will at times remain in the scows for hours with the doors open. Jetting may be resorted to in such instances.

The ladder dredge working in free sand experiences some difficulty in maintaining full buckets, due to the agitation of the sand and the consequent loading of the buckets with a mixture of sand and water with sand in suspension. In sand and mud, therefore the buckets are run at a low velocity, or the same effect is obtained by spacing them further apart by the interpositon of a link

between each pair of buckets. In refractory material, the bucket chain is speeded up to get the benefit of impact or else the buckets are spaced more closely.

The Table page 112, is an effort to group the four dredge types in the order of their preference for each of the classes of material usually encountered in dredging operations. Beginning at the left with "Mud," the various soils are listed in the order of their difficulty of removal from the dredging standpoint. The first named dredge under each heading is the type best adapted to that kind of soil, the second the next most desirable, and so on. It must be borne in mind that this selection is made purely upon the basis of the nature of the material, assuming that all other conditions are ideal for the operation of each dredge in the material named, and that the soils are homogeneous and free of obstruction.

1. Mud.	2. Mud and sand.	3. Coarse sand.	4. Fine sand.	5. Sand and gravel.
Hydraulic	Hydraulic	Hydraulic	Hydraulic	Dipper
Grapple	Grapple	Ladder	Dipper	Ladder
Dipper	Dipper	Dipper	Ladder	Hydraulic
Ladder	Ladder	Grapple	Grapple	Grapple

6. Gravel.	7. Stiff clay.	8. Indurated clay or hard pan.
Ladder	Dipper	Ladder
Dipper	Ladder	Dipper
Grapple	Hydraulic	
Hydraulic	Grapple	

In regard to the character of the bottom soil, therefore, the hydraulic and dipper dredges hold the high scores, but upon a consideration of the other factors, it will be found that the grapple type will assume a more important role.

b. In some localities, the War Department Engineers have set aside certain areas, called free dumps, over which it is permitted that dredged material be deposited from scows. Disposal in this manner is regulated by the War Department and supervised by inspectors in their employ, who are stationed on the tow boats taking the scows to and from the dump, and whose salaries are paid by the dredging contractor. Buoys and lights on the dumps must

also be maintained by and at the expense of the contractor. The cost of such deposit is reduced to the per cubic yard basis and is a function of the number of yards handled and the cost of the scows, tug boats, crews, inspection and buoy maintenance for any day, involving the number of round trips made in one day and the number and size of scows in each tow. Tidal and seasonal weather conditions may have an important bearing and must be discounted. In bad weather, dredging operations may even be entirely suspended for a time because of the inability of the tugs to make the tow. In some harbors, located on or near the seaboard, material is towed to sea and dumped. The total cost of the dredging then is the sum of the cost of the actual operation of digging by bucket machines and loading the scows, plus the cost of transportation to the dump, including, of course, the use of the plant. Should no free dump be available, or the towing distance be too great, the alternative is the hydraulic rehandling of the scowed material into an impounding basin.

(*c*) The stationary hydraulic dredge requires a nearby impounding basin or a place to receive and contain the pumpings, and the cost and other features of this indispensable adjunct will very often decide for or against the use of suction machines. Provided, therefore, that the material to be dredged is such as to permit of hydraulic removal, a study of the topography of the adjacent terrain and of the hydrography of the abutting shore line is made for the purpose of determining its availability for impounding uses and estimating the expenditures necessary for the acquisition of the property or of the filling rights and for the construction of the basin. The ideal basin will have the following features:

1. *A Large Capacity for a Small Construction Cost.*—The principal item of expense is that of the enclosing or retaining structure, the bank or dike, and it is obviously an economic advantage that the initial and maintenance banking cost per cubic yard of basin capacity be small.

2. *Maximum Increase in Property Value Accruing from*

the Fill.—Whether the filling effects the rehabilitation of swamps and marshes or the reclamation of submerged waterfront areas, it naturally enhances the value of the property. For this reason, the basin privilege may often be obtained from land owners without charge, obviating the necessity of purchase. In some cases the positions of creditor and debtor may even be reversed. Should the basin project beyond the shore line, questions may arise as to riparian rights, the slip rights of adjoining owners, the location of bulkhead lines established by local or government authorities and the granting of license to build by those same departments.

3. *A short pipe line from dredge to basin.*

4. *Easy Accessibility.*—By this is meant a minimum cost of pipe line communication from the pontoon line to the basin, or, in other words, a dearth of expensive pipe trestles and of obstruction to laying the line.

5. *A Low Final Grade.*—High elevations of discharge pipe mean increased head on the pump and reduced output.

6. *Natural Disposal of the Effluent.*—The great quantity of water accompanying the soilds must be returned, in the great majority of cases, to the source from which it was pumped. At the same time, it is desirable that the waste-weir or sluice be remote from the pipe discharge in order to give opportunity for the precipitation or impounding of the solid matter carried in suspension in the water. Should such location of the sluice-box preclude the natural flow of the effluent from sluice to source, an artificial canal or flume becomes necessary.

In making an economic choice between bucket and hydraulic plant for a dredging operation in so far as the impounding basin is concerned, the problem may be stated briefly thus: Does the accrued value of the basin property plus the saving effected by direct hydraulic removal in lieu of bucket dredging and scowing away justify the expense of the construction of the empty basin, comprising acquisition of property and the initial and maintenance cost of banks, sluice, drainage canal and pipe lines?

The quite common use of impounding basins for the disposal of bucket-dredged material presents a different problem. Here the contents of the scows are dumped to a pump located at the basin and rehandled hydraulically into it, in which case, the rehandling and basin expense are appurtenant to the cost of the bucket dredging.

(*d*) The first feature of the fourth factor, viz. the kind of plant available, is self-evident. Naturally the selection of plant must be made from that which can be brought to the job without prohibitive transportation expense. The project may clearly be a bucket job and yet, because of the impossibility of obtaining enough bucket plant to complete it on time, the necessity may arise for the assistance of available hydraulic machines.

Dredges of the same type often have distinguishing features and characteristics peculiar to themselves. This grapple or dipper is slow and that one fast; or this suction dredge is no good on the long pipe lines; or this dredge is underpowered, or a poor steamer, or a coal glutton; this machine has a better captain, or better quarters for the men and therefore is better able to hold her crew; or this pump has a better cutter head and this one has too light a ladder to hold the cutter down in hard stuff, etc., etc. Naturally those units are desired which will give economically the greatest output.

(*e*) As to space limitations and interference with traffic: The size and form of the area to be dredged and the presence of traffic may be an important consideration in the selection of type and even in the choice between dredges of the same type. Hydraulic dredges with radial feed about the stern spud require considerable space for efficient operation because of their pontoon lines, possible pipe trestles, the great width of cut and the presence of swinging wires on both sides. Those having swinging ladders can work in more confined areas, due to the narrower width of cut and the absence of swinging wires. Bucket dredges must have enough room for towing scows to and from the machines and for handling the scows at the dredge. It will be remem-

bered, that, at the commencement of the loading of a scow, almost its entire length extends forward beyond the bow of the dredge and also that dredges are usually rigged for right-handed digging, i.e. with the scow on the starboard side. The head of a narrow slip, therefore, may be practically inaccessible to a clam shell dredge and its accompanying scow, or may necessitate the use of a grapple and scows of smaller capacity. Limited space or traffic congestion may give rise to the necessity for the use of bucket dredges having sufficient spud equipment to obviate the necessity for wires and anchors. In throwing up banks or in dredging drainage and irrigation ditches, it is desirable to have dredges of small beam, where the conditions are such that the narrowest possible cut is all that is required. Small grapples and dippers swinging 5/8 to 1½ yd. buckets on long booms are generally employed for such work and are called banking machines. Some such are equipped with bank spuds in lieu of the usual type. Bank spuds are inclined away from the dredge and bear upon a small grillage resting on the top of the bank, thus maintaining the dredge upon an even keel in resisting the listing moment of the long boom.

(*f*) Both the existing depth and the depth to be dredged are considerations in the plant selection. Since the scows being loaded by grapples and dippers extend forward beyond the bow of the dredge and in advance of the dredged cut, the before-dredging depth of water must be sufficient to float the loaded scows in order to permit the dredge to work. This flotation depth is usually about 10 to 12 feet. If the natural water is too shoal, therefore, for loading scows at all stages of the tide, a channel called a "pilot cut" must be dredged for them. The material from such preliminary work, obviously, cannot be scowed away, but must simply be "cast over" to one side, forming a spoil bank, which is removed later in scows. A dredge may do its own pilot cutting, but a more efficient method is the use of smaller, less expensive, long-boom machines.

Hydraulic dredges require flotation for a sufficient length of their pontoon lines to allow the necessary swinging

freedom and advance motion. Three or four feet will float the ordinary pontoon for a 20 inch machine. The draught of the dredge itself may be a factor. Dredges must float to operate. The process of making flotation depth for their own hulls is termed "digging themselves in." Considerations of this nature, more particularly in ditching and banking operations, may establish a preference for light draught machines.

The final depth specified and the vertical distance between the original and final depths, which is called the "depth of cut" or "height of bank," may influence the choice of plant. A grapple machine is not limited to any depth except by the length of the bucket wires and the wire capacity of the drums. The dipper is limited first, by the length of dipper stick, and, second, by her power to develop the necessary forward thrust of the dipper, which decreases as the depth increases. A dipper will seldom be economical in depths greater than 35 to 40 feet. The maximum depth of which the hydraulic is capable is a function of the length of ladder and the design of the ladder hinge. For all around work, a 20 inch or larger machine should be designed to dredge to 38–42 feet below the water surface, although the requirements will vary with the locality and purpose for which the machine is built. The depth capabilities of the elevator will be controlled by the length of ladder and the engine power. The deeper the water, the greater the work done in the same time because of the increased lift.

Hydraulic and ladder machines are better adapted to small "depths of cut," or "height of bank" than are grapples and dippers.

(*g*) Finally, time may be a most pertinent element of the problem. An emergency job of some magnitude may require that the considerations of economy and efficiency be temporarily waived to a certain extent in order that the complete removal of a given yardage be accomplished in a certain time. The rate of the dredging may be the governor of an entire project.

Construction progress on piers, wharves, shipways, dry docks or ship launchings may hinge upon the dredging. It is hardly necessary to enumerate the multifarious ways in which the completion of dredging by a given date can and does acquire great importance. The problem then is to assemble a plant that will do the work in a hurry. It may involve the expense of the construction of an impounding basin to receive rehandled material from bucket dredges, even though scowing away be more economical. It may mean use of bucket dredges in lieu of less expensive hydraulic machines, because of the ability to work several bucket machines where but one pump could operate. It may mean the employment of pilot machines which would be unnecessary if there were sufficient time to permit the dredging to pursue its economic course. Direct pumping may be necessary in order to get large output, even though the cost of the basin be otherwise prohibitive.

Plans, Specifications and Contracts.—There are several principal bases upon any one of which a dredging contract is written, the preference depending in great measure upon the definiteness and degree of certainty of the information as to the extent, nature and working conditions of the proposed project. The completeness and text of the specifications and contract will naturally depend upon the basis adopted. The choice usually lies between

1 The unit price basis, by which the contractor is paid a certain price, fixed by the agreement, for each cubic yard of material dredged, measured either in the scows or in place in the cut.

2. The cost plus percentage basis, by which the contractor is paid the actual cost of the work plus a fixed percentage of that cost.

3. The cost plus fee basis, by which the contractor is paid the actual cost of the work, plus a definite sum of money or fee, fixed by the contract.

4. The lease or rental basis, by which the contractor is paid a fixed rental for his plant for the period of its use, in full compensation for the performance of the work specified.

5. The cost plus rental basis, by which the contractor is paid the actual cost of the work plus a fixed periodical rental in compensation for the use of his plant and services.

6. The lump sum basis, by which a sum of money is mutually agreed upon as full compensation for the entire project complete, and is usually paid out to the contractor in monthly installments in amounts varying with the estimated quantity of material removed during each month.

The first method is the most common and is in general favor with the owners or parties footing the bills. They have the satisfaction of knowing in advance within narrow limits the ultimate cost of the work to them. Where an abnormal element of uncertainty exists, however, as to the extent of the work, the nature of the material or the condition of the labor and supplies markets, it is not only manifestly unfair to the contractor to pin him down to a definite yardage price, but it is very probable that the work will cost the owner more money than would be required under some other form of contract. Under such conditions, the contractor will usually bid high to cover possible contingencies, which are thus paid for whether or not they materialize, and the owner had done better to accept a basis of payment such as numbers 3 or 5 above. The sixth basis is seldom employed in dredging, because of the discrepancies between estimated and actual yardages.

Dredging is no exception to the rule, prescribed both by economy and ethics, that the information furnished bidding contractors be as complete as it lies within the power of the engineer to provide. Rather is it a branch of contracting, to which, because of its inherent uncertainty, this is particularly applicable.

It is not necessary to review here the general clauses, indigenous to all dredging contracts. An outline of the specific information that should appear in plans and specifications accompanying invitations to bid a unit price follows:

1. A map of the waterway showing the area to be dredged and the places of deposit; the existing depths of water over this area and in adjacent reaches, recorded from recent

soundings; the topography of the places of deposit if in the dry; and finally the locations of borings.

2. A description of the principal characteristics of the waterway, as to tidal range, freshets, ice, etc.

3. A clear exposition of the work to be done: the length, width and depth of the proposed channel, the method of disposal and the approximate quantity of material to be removed, place or scow measurement.

4. A definition of the pay quantities, the method of measurement and, if necessary, the ratio for the conversion of scow to place measurement and vice versa.

5. The limits of the cross section of the proposed channel, the side slopes and the overdepth allowance, and the amount of money to be deducted for each yard removed from outside these limits.

6. The character of the material to be dredged as determined by borings, samples of which should be available for examination; whether original bottom or sedimentation; and a definite limit to the difficulty of the material to be removed without additional compensation.

7. A clear statement of the basis of acceptance of dredged sections.

8. A definite line of demarkation between the duties of the contractor and the engineer as to ranges, buoys and field work generally.

9. Appurtenant items of expense to the contractor, such as inspection, dump and basin maintenance, etc.

10. Responsibility for dikes, sluiceways and pipe lines.

11. Limits for starting and completion, if desired, and the order of work.

Obviously, with the other forms of contract, some of the above data is superfluous, but on the other hand, certain additional information is necessary. In those contracts involving a determination of the cost of the work, the make-up of that cost must be clearly defined, and in those having the rental feature, an understanding is necessary as to the plant leased, towage charges, wages of crews, fuel and supplies, and precisely what lost time is

chargeable to the contractor and what to the lessee. The latter may be protected by a specified guarantee of output for each dredge. For a portion of the original dredging work at the Hog Island Shipyard, hydraulic dredges were leased with the understanding that reductions in output below 6000 yards per 24 hour day through a pipe line not longer than 3500 feet would entail proportionate reductions in rental. This guarantee, however, was subsequently waived, owing to the material being more difficult than the mud and sand specified.

Scheduling.—In order to predetermine the size of the plant and the most advantageous disposition of the units thereof, that the project may be completed within a given time, a dredging schedule is drawn up. Even though the uncertainities of dredging render it impossible that the schedule embody the same degree of precision and expectancy ascribed to those of other classes of work, yet it is very necessary to the successul prognostication of the results and very useful in the coordination of the units engaged. The schedule is a program of operation, showing the number and names of the machines employed upon each division or zone of the work, the length of time from date to date that each item of plant remains thereon, the yardage assumed to be the daily average output of which each dredge is capable, and the total yardage to be removed from each zone. It is an effort so to locate each dredge as to provide conditions to which that machine is best adapted, and to coordinate to the fullest extent the project as a whole by intelligent anticipation of the growth of space and depth limitations affecting the relative location of the dredges. The success of the schedule will depend in large measure upon the correctness of the assumed daily average output of each machine, which must be low enough to take care of a reasonable amount of lay time due to repairs, etc., and upon the ability of each dredge to endure through the life of the job without serious accident. The fundamental weakness of a dredging schedule is that the output is dependent upon a small number of units of large capacity,

so that a loss of any one of them entails a large percentage of reduction in the working plant.

As always in problems of this character, the best method of attack is first to define specifically the ideal schedule and then so to modify it as to incorporate to the best advantage and with minimum deviation from the ideal all the practical considerations and circumstances of operation that must be taken care of. A form similar to that of Fig. 38, page 122, is very helpful. The entire area to be

DREDGING SCHEDULE

Zone	Est. Yardage		Dredge	Daily Av'ge	Working Days	Quota	April	May	June	July	Aug.
	Bucket	Hydr'c					7 15 22	7 15 22			
A	300,000	—	No. 1	4,000	25	100,000					
			No. 2	3,000	25	75,000					
			No. 3	2,500	50	125,000					
B	200,000	—	No. 1		25	100,000					
			No. 2		34	100,000					
C	75,000		No. 3		30	75,000					
D	—	5.0,000	No. 4	5,000	60	300,000					
			No. 5	6,000	34	200,000					
E		etc.		etc.							
Rehandler			No. 6	12,000		575,000					
Totals											

Date — Approved —

FIG. 38.—Convenient form of schedule.

dredged is first divided into a number of blocks or zones and the yardage in each is computed. The size and boundaries of the zones will vary with the nature of the job, but, where possible, it is convenient to have them defined by such tangible limits as may exist, by the ranges establishing the dredge cuts and by the dividing lines between bucket and hydraulic areas. The location of shore pipe lines and pipe trestles is a factor in the hydraulic zone layout, since the location and field of operation of each pump dredge is dependent thereon. By making the horizontal lines representing the periods of operation in the zones a separate color for each machine, the itinerary of each dredge can readily be followed down the page.

Estimating the Cost.—The complete cost of a dredging project from the time of its inception comprises five principal items, as follows:

1. Cost of preliminary engineering.
2. Cost of permits, licenses and acquisition of property or filling rights for impounding basins.
3. Cost of preliminary structures.
4. Cost of operation of the dredging plant.
5. Cost of maintenance of the dredged depths.

The first consists of the salaries of engineers, office force and field parties engaged in making the preliminary surveys, exploring the site and preparing plans, specifications, estimates, schedules and contracts; the cost of their equipment and supplies; the cost of labor, equipment and supplies used in making borings and probings; overhead, comprising salaries of executives, legal advisory talent, office rent, insurance and incidentals.

The second is self-explanatory.

The third includes the cost of construction of dikes, sluice-ways, drainage ditches, shore pipe lines, involving excavation, cribbing, trestles and pipe laying; the cost of construction plant, repairs, depreciation and sinking fund; cost of materials, labor, supplies and transportation; cost of field office, superintendence and general overhead.

The fourth item is the cost of the actual removal of the material and obviously is the largest part of the cost of the job. Only when the engineer is directly operating the dredging plant will he be concerned in detail with all the numerous components making up this item. His point of view is influenced by the nature of the contract. If the work is to be paid for upon a per cubic yard basis, he will add to that unit price, the cost of operating items not covered thereby, as dump and basin maintenance, superintendance and inspection, hydrography and overhead, after reducing them also to a yardage basis. If the contract be one of lease, he figures for each plant unit the cost per diem of the bare boat, the crew, grub, fuel and such items as are not included in the bare boat rental, after

which, from an assumed daily output, he prognosticates the length of duration of the lease. To this, of course, must again be added the items of dump and basin maintenance, etc., as above.

The components, in detail, of the cost of operation are as follows:—

(a) *Plant*...........	Transportation
	Repairs
	Depreciation
	Sinking Fund
	Insurance
(b) *Labor*...........	Dredge crews
	Tug crews
	Miscellaneous plant crews
	Pipe line men
	Insurance
(c) *Supplies*........	Fuel, oil and waste
	Food and miscellaneous supplies
	Furnishings
	Tools
(d) *Dump and Basin Maintenance* ..	Buoys
	Lights
	Dike patrol
	Dike and sluice repairs

(e) *Superintendence and Inspection.*

(f) *Hydrographer's Force, Equipment and Supplies.*

(g) *General Overhead, both Contractors and Engineers.*

The fifth item, maintenance of dredged depths is a subsequent expenditure, but may be a factor in the selection of channel location. It involves not only the cost of redredging, but also the maintenance of controlling structures.

CHAPTER X

PRELIMINARY CONSTRUCTION

Dikes for River Control.—Dredging and the maintenance of dredged depths is intimately related to the subject of the characteristics and regulation of rivers. This, however, is much too broad and far-reaching in its scope to be included within the narrow confines of this small book, and will merely be summarized with maximum brevity in order to indicate its bearing upon our title subject.

The problem is the prevention of the silting-up and dislocation of dredged channels and areas by the agencies of sedimentation and scour. Since the surest cure is the removal of the cause, let us go back to the source and review hurriedly the marshalling of the forces of nature for the destruction of the works of man. The "rainfall," i.e., both rain and melted snow, suffers one of three fates: Part of it is evaporated, part penetrates the earth surface to become "ground water," which, pursuing subterranean courses, eventually reaches the river, and a third part remains upon the surface, constituting the surface drainage and creating the mountain torrent and, finally, through brook and creek, reaches the river. The "run-off" for a particular water-shed is the rainfall, less the evaporation, and thus comprises both surface drainage and ground water. The percent of run-off will be influenced by many factors, principal among which are the character of the soil, the slope, the vegetation, the climatic conditions and the degree of concentration of the precipitation throughout the year. The quantity of sediment and its rate of progress to the river depends upon the run-off and the factors upon which the run-off is dependent. The considerations thenceforth are the ability of the river to transport the sediment and to scour its banks and bed, and the study of

the laws or characteristics governing such scour and deposit.

The sediment-bearing power of flowing water is a function of the velocity of flow. The velocity is a function of the slope of the river and its cross section. The velocity is not uniform, however, throughout the cross section. Near the banks and the bottom it is slower because of frictional resistance, and the maximum velocity will obtain somewhat above the mid point of the greatest depth. Sediment may be transported either in suspension or by being rolled along the bottom. The heavier the material, the greater is the velocity required. A velocity that is just sufficient to carry a particular class of material is unable to pick up that same material from a position of rest on the bottom. The deposition of sediment is caused by the checking of the velocity of the soil-bearing current due to obstruction or change in grade or cross section.

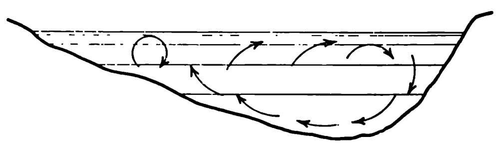


Fig. 39.—Secondary currents in the cross section of a stream.

The principal water currents existing in a river are of two kinds; first, that in the direction of the river slope due to gravity; and, second, the transverse currents caused by change of direction of the river's course. The velocity of the flow along the outer bank of a bend is naturally greater than on the inner, and, further, the axial current in resisting the change in direction, creates a radial, dynamic pressure acting toward the outer bank and setting up currents in that direction. By actual observation it has been found that these cross-currents move toward the outer bank near the river surface and toward the inner bank near the bottom or wetted perimeter of the cross section, somewhat as shown in the figure 39.

Thus it is the outer bank of a river on a bend that is subjected to scour and it is near the outer bank that the

deepest water will be found; and the river, by simultaneously building up by deposit the inner bank of the bends, tends ever to an increasingly winding course. The fact that rivers of the least slope have the most bends is due in part to the greater relative influence of these cross-currents born of the radial pressure.

The weights of bodies that can be moved by the pressure of a current vary as the sixth power of the velocity, and the diameters of the bodies as the square of the velocity. Hence, an increase in velocity causes far greater increase in transporting capacity. Mansfield Merriman, in his Treatise on Hydraulics, gives the following table of approximate values:

Velocity of 0.25 feet per second moves fine clay.
Velocity of 0.5 feet per second moves loam and earth.
Velocity of 1.0 feet per second moves sand.
Velocity of 2.0 feet per second moves gravel.
Velocity of 3.0 feet per second moves pebbles 1″ in size.
Velocity of 4.0 feet per second moves spalls and stones.
Velocity of 6.0 feet per second moves large stones.

Rivers are opened to navigation either by the dredging of a deep water channel in their beds or by canalization. Minimum first cost and maintenance expense involve a coordination of the factors, minimum initial excavation and redredging. Often, the natural agencies of scour and sedimentation can be so regulated by artificial means as to reduce the cost of the maintenance of the dredged cuts by such an amount as to warrant the cost of those means. Such regulation takes the form of velocity control both in amount and direction by artificial changes in cross section and water course, involving the construction of training and spur dikes and bank protecting structures. To stabilize the course of the river and therefore the channel location, it may be necessary to prevent further undulation of course by protecting the outside bank of a bend against further recession. This may be accomplished by some sort of pavement upon the exposed slope such as vegetation, brush fascines, mattresses, sand bags, concrete bags, riprap or an apron of timber or concrete; or by a sheet pile

revetment; or by a timber or concrete bulkhead. Or the bank may be retained by a series of dikes or jetties projecting out from the shore into the waterway. Such dikes are called spur dikes, and may be either solid or permeable, *i.e.*, they may be an impervious current stop or they may have openings to permit the passage of the water at a reduced velocity. The current instead of attacking the bank, impinges upon the spur dikes and expends its energy in the creation of secondary currents and eddies until its velocity is so reduced in the area between dikes as to cause it to unload its suspended material. Again, it may be desired so to reduce the effective width of the river as to cause an increase of velocity sufficient to create scour where sedimentation had previously occurred and caused expensive redredging. Spur dikes act in this manner to a certain extent, but more often a training dike, which is nearly parallel to the water course, is employed. The training dike is generally of much greater length than the spur dike, and the resultant narrowing of the stream causes higher than original velocities for the same discharge. Sometimes an island is so situated in the stream that it becomes in effect a training dike upon the connection of its upper end with the main land.

Man-made dikes are of several principal types as follows:

1. Earth Embankment, with or without protective paving.
2. All-Stone Embankment, the submerged portion usually a rip-rap heap, deposited upon a brush mattress, and the superstructure either rip-rap of larger dimensions or coursed rubble.
3. Composite Dike of rip-rap substructure surmounted by a gravity wall of masonry or concrete or by a timber crib.
4. Single row of sheet piling, driven between wales attached to plumb, round piles and braced by batter piles. This type is well adapted to the permeable spur duke, as any desired percentage of permeability may be obtained by varying the width of aperture between successive sheet piles.

5. Parallel rows of sheet piling, as above, enclosing a fill of suitable material and tied together through the fill with wire rope, chain or rods. Additional lateral stability may be provided by spur piles in both directions transversely in the fill.

6. Timber Crib with good heavy filling.

In choosing a typical section, the designer should have in mind the forces to be resisted, *i.e.*, the "loading" of the dike. Since we are treating only of such dikes as are built in the river and not of the "levee" which confines the river itself, the hydrostatic head due to differences of elevation upon the two sides will be negligible, and the only loads to be considered are the weight of the structure itself, current scour, wave action and ice. An analysis of wave action reveals five components:

1. The normal impact due to the waves' momentum.
2. The upward force parallel to the face of the dike tending to sheer off protruding members.
3. Hydrostatic head due to the increased elevation of the water surface.
4. Internal pressures due to the imparting of impulses to the water and air contained within the interstices of the dike.
5. The back suctions as the wave recedes.

Ice may create a very considerable thrust against the dike, limitied in intensity only by the ultimate crushing strength of the ice.

For training purposes, in localities where the quarries are available, the stone dike probably gives the most complete all-round satisfaction. A brush mattress is first built somewhat wider than the asssumed base of the stone pile and is sunk between guide piles by loading it with stone. For the substructure and the core of the superstructure, the stone my range in size from one man stone to about four ton derrick stone, or practically the run of the quarry, but, for the superstructure facing and coping, only large sizes should be used, whether the section be rough rip-rap or squared stone rubble, because the separate units must

have sufficient weight to resist dislodgment and transportation by ice and waves. For the same reason, the superstructure is laid with frequent headers to give the necessary bond. The small stone is deposited by stone pans or scale boxes, which are simply rectangular trays open at one end and handled by a derrick. The derrick stone is placed by the use of chains and stone hooks. The maximum slope of the underwater portion or substructure will be 1 to 1, but the superstructure wall may be laid up more steeply, if desired, to economize through the saving in width of base for a given height. For estimating purposes, the body of the dike so built will run about 1½ tons of stone per cubic yard of dike for granite, gniess or rock of a similar weight, and the facing and topping stone about 2 tons to the cubic yard.

Dikes for Impounding Basins

The principal component structures of the complete impounding basin are:

1. The enclosing structure or "dike."
2. The "sluice" or "waste-weir" for the discharge of the pumped water.
3. The occasionally necessary ditch, canal or flume for the conveyance of the effluent from the sluice to its source.

The type of dike best adapted to a particular case and the most economical design and method of construction will depend primarily upon the location of the proposed basin with respect to the normal beach line, i.e. whether it be upon the land or in the water, or in other words, "dry" or submerged." Obviously, the "dry land" dike is the simpler and less expensive general type, involving less depth of fill, and less potent destructive forces to resist. This type we shall first consider.

Dry Dikes.—Most commonly the Dry Dike is an earth embankment, thrown up by hand, by steam shovels or by drag-scrapers. The nature of the soil will influence in a measure the dimensions of the bank, but, generally, for a height of more than 6 feet, the top width should be not

less than 5 feet, and the side slopes not more steep than 1 on $1\frac{1}{2}$. Aside from the direct hydrostatic and earth pressure exerted by the pumpings, the most common destructive agents threatening the stability of such a dike are as follows:—

1. *Scour.*—A concentration of flow from the discharge pipe along a bank may so scour and disintegrate the inside slope as to endanger the structure. Once having broken through, the escaping water widens the gap and "melts" the embankment quite rapidly. The remedy, of course, is either the diversion of the flow by shifting the pipe line or by the use of baffle boards, or the protection of the bank with brush mattresses, sand bags or sheeting.

2. *Wave Action.*—If the area of the basin be such as to expose a considerable expanse of water to the winds, the banks may be reduced by wave forces unless protected as above.

3. *Frost.*—The soil comprising an embankment built during the winter may be so frozen as to cause subsequent settlement and even the destruction of the bank after the spring thaw. The internal portion may remain frozen for some time after the thaw and cause trouble when not expected. Again, spring thawing of the frost in an old bank may cause such softening as to decrease the stability of the structure.

4. *The Muskrat.*—Should an embankment be in service for longer than one dredging season, it may become necessary to guard against the ravages of the muskrat, which small rodent is the sworn enemy of the mud bank. As soon as the mud is of sufficient consistency to "stand up" over his operations, he excavates tubular tunnels in all directions until the dike is so honeycombed as to be unsafe.

Any green embankment receiving pumpings should be vigilantly patrolled until such time as it is known to be secure. Vegetation should be encouraged.

Land dikes may also be built of timber sheeting: either a single fence preferably of two layers of plank with lapping joints and banked with earth on one side to lend stability

and prevent leakage or two parallel lines of sheeting about as far apart as their height, tied together with wire or rods, and filled with earth. It is sometimes possible to economize on the banking expense by raising a fill a few feet at a time, either by hand made embankments of small size or by plank retainers, resulting in a stepped dike.

Wet Dikes.—Enclosing the "wet" or "submerged" impounding basin presents rather more of a problem. Here we may have extensive wave action with which to contend, together with the tides, and tidal and other currents, often increased in intensity by the obstructive nature of the basin and causing rapid scow of the original bottom at the toe of the dike. To such an extent has this happened as to establish a considerable flow under the dike structure between the contained water and that outside. Moreover, as previously suggested, the dike is of greater total height, due to the addition of the submerged portion and must resist pressures of greater magnitude. Dikes for this purpose may be classified under one of the six following captions:

1. The Mud Bank,
2. The Mud Fence or Single Row of Sheeting,
3. Parallel Rows of Sheeting, filled with Earth.
4. The Timber Crib,
5. The Stone Dike,
6. The Bulkhead or Marginal Wharf.

The first is simply a mound of earth cast up by a long-boom grapple dredge from the bottom soil. Although often employed with varying degrees of success, it is frequently of doubtful stability and permanence. The material of which it is built is saturated and suffers therefrom in angle of repose. It may be easily so soft as to be incapable of "standing up" above the water surface. Unless protected upon its slopes by more resistant material, it is easily scoured and melted away by wave and tide action. The depth of water in which it is to be built is an important factor.

The mud-fence is simply a tight vertical wall of continuous sheet piling, driven between guide wales, supported at in-

tervals by round piles and stabilized against the thrust of the pumpings by spur or batter piles or by tie rods and anchorages. The sheeting may be a single thickness, or two layers, shiplapped, or Wakefield piling, depending upon the degree of tightness necessary to prevent leakage, as determined by the nature of the backing and pumpings. Wakefield is a built up tongue and groove piling, consisting of 3 planks fastened together as in Fig. 40. The fastening is effected by machine bolts, by wire spikes driven through

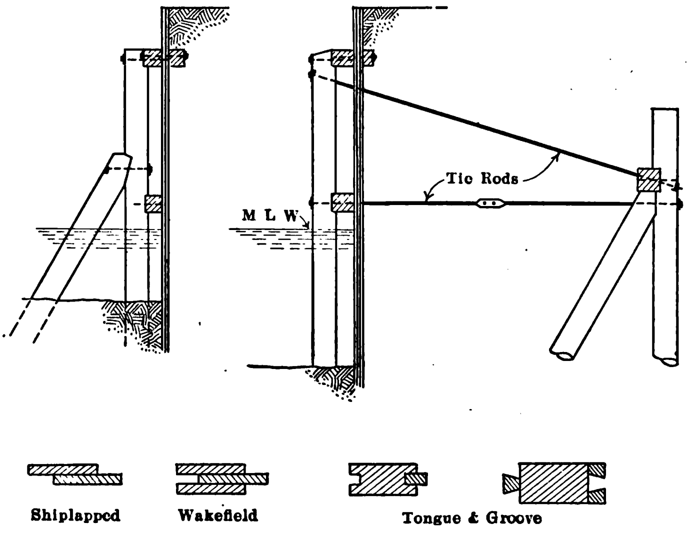


FIG. 40.—The mud-fence.

and clinched or by a combination of the two. A fourth method employs so-called splines, set in grooves in the sheet pile proper or nailed to the edge thereof. The dimensions of section and the length of the sheeting will depend upon the nature of the bottom, the depth of water, the height of the structure and the filling conditions. The size of the wales, spacing of round piles and anchorages or spur piles are determined from a study of the pressures acting upon the fence, by methods which will be outlined subsequently. The tie rods should be upset and provided with turnbuckles, by which an initial stress is set up in them

to overcome the inaccuracies of framing the spur pile connection and to bring the surfaces into full bearing so that the resistance of the anchorage may be developed in the beginning before distortion takes place. This is very necessary to the preservation of the alignment of the retainer. The tie-rod washers are theoretically proportioned to distribute the bearing sufficiently to obviate local failure. Before commencing to pump into the basin, it is often advisable to back the mud fence with a bank of mud, or, if practicable, of more suitable material.

FIG. 41.—Long boom banking machine (Delaware Dredging Co.) filling a timber crib dike.

Conditions of greater depth and softer bottom may require the construction of a heavier and more expensive structure. Parallel mud fences, facing in opposite directions, almost as far apart as their height above the mud, tied across and braced by spur piles between them and filled with earth, form a substantial retainer which may prove best adapted to a particular problem.

The timber crib affords a useful expedient where the bottom is either of rock, prohibiting the penetration of piles, or of soft mud, affording scant lateral resistance for the sheet pile structure. A description of it is hardly

necessary. It is simply a basket of squared, flitched or round timbers, successive layers of which are laid horizontally at right angles to each other, notched and spiked at the intersections, forming a cellular box which is subsequently filled with earth or preferably heavier material. It may be floored and lined with plank to secure greater fill-tightness, or the floor may be omitted and the lining planks driven down as sheeting into the mud below the crib. The bottom having been levelled as much as possible by dredging, the crib is built to fit the prepared surface. It may be constructed in the dry in sections and sunk by filling, or built up floating in the water, sinking under its own weight as the walls rise, and guided to the bed by guide piles. The width of the crib at the base is generally almost as great as the height. The rear face may be stepped, and the front face battered.

The stone dike, except under the most favorable conditions of market and working facilities will rarely prove economical. Little more need be said about it in this connection. It is generally quite pervious to the pumpings, requiring, for tightness a mud or other suitable backing.

By the bulkhead or marginal wharf is meant a retaining structure permitting deep water at its face for vessel flotation. It is not essentially a dike, but is mentioned here for the reason that, under certain conditions, the enclosing of an impounding basin by such a structure, the province of which is not only to serve as a dike, but also to make the property available for wharfage purposes, may prove to be the economical solution. The foregoing dikes, such as the timber crib or the parallel rows of sheeting will often involve considerable cost, entailing the expenditure of a large sum of money for a structure, the sole function of which is to serve as a dike, so that the enhanced value of the bulkheaded property may warrant the greater initial outlay. If the basin is ultimately to be used as a wharf property, it is obviously in the interest of economy to accomplish this end in one operation rather than subsequently to sup-

plement a dike with a wharf structure, unless there be attenuating circumstances.

Spur Piles.—Of the above six types of wet dikes, it will readily be seen that Numbers 1, 4 and 5, and Number 3 partially, are gravity retainers, and that Numbers 2 and 6, and to some extent Number 3, employ the spur or batter pile to resist the overturning tendency. It would appear, therefore, that the subject of spur piles is of sufficient importance to merit discussion here. Moreover, the diversion, if it be such, is further excused by the tendency among some contractors and even engineers to give inadequate attention to the spur pile details both in design and construction. Not only is this true of the dike, but of bulkheading structures generally, wherever the spur pile is employed, and many failures may be attributed to this fact alone. In the first place, because of the expense of providing special inclined ways for driving the batter piles, they are frequently driven by tilting up the leads of vertical pile drivers, resulting in insufficient batter to develop the horizontal resistance required. An inclination of 30 degrees to the vertical is entirely practicable in the great majority of cases and should be insisted upon. Again, whether through failure to realize fully the nature and extent of the forces acting, or through the desire to economize in framing and hardware costs, the head of the spur pile is often inadequately retained to develop the full horizontal resistance.

Let us discuss for the moment the spur pile in general. Assume that a pile is driven on a batter of 1 to 2 to such penetration as to develop a safe axial bearing value of 12 tons or 24,000 pounds. The vertical component, Fig. 42, is about 21,400 pounds and the horizontal 10,700 pounds. The pile then is capable safely of resisting a horizontal thrust of 10,700 pounds if—and herein lies the difficulty—the head of the pile is held down by a force equal to the vertical component, 21,400 pounds. In bulkheads of the relieving platform type, this downward resistance to the upthrust of the spur pile, is furnished wholly or in part by

the weight of the fill upon the platform, but in other types of retaining structure, such as the cases in point, or in marginal wharves of the above-water pile and platform design, it becomes necessary to depend upon the resistance to pulling of a vertical pile to which the spur pile is attached, and it is this attachment which merits emphasis.

If framed as in Fig. 40, page 133, the depth of "gain" in the plumb pile must be sufficient to give a horizontal bearing surface of such area as to keep the unit bearing

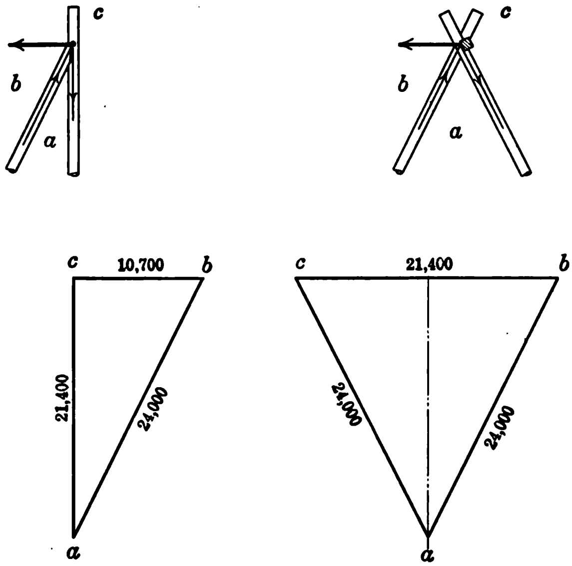


Fig. 42.—Spur pile resistances.

within the allowable limit. If the safe end-grain bearing value is 1000 pounds per sq. in., the area required for the above case is 21.4 sq. in., which, in a 14 inch pile, will obtain at a depth of about 3 inches. Moreover, the length of plumb pile above the notch must be great enough to preclude failure by shearing with the grain. It is not always practicable, however, to drive spur and plumb pile in such relative position as to permit a fastening of this kind. In many instances, the batter pile must be placed alongside a bent of vertical piles, in which position, the problem of

sustaining its upward reaction often presents difficulties. It is manifestly not enough simply to bolt the spur and plumb pile together horizontally at their intersection, because, even though the bolt be of sufficient size to take the shear, the fastening will fail through the bending of the bolt and the crushing of the wood fibres in the bolt hole at the point of contact of the two piles. The most convenient and efficacious arrangement of this detail in high timber platform

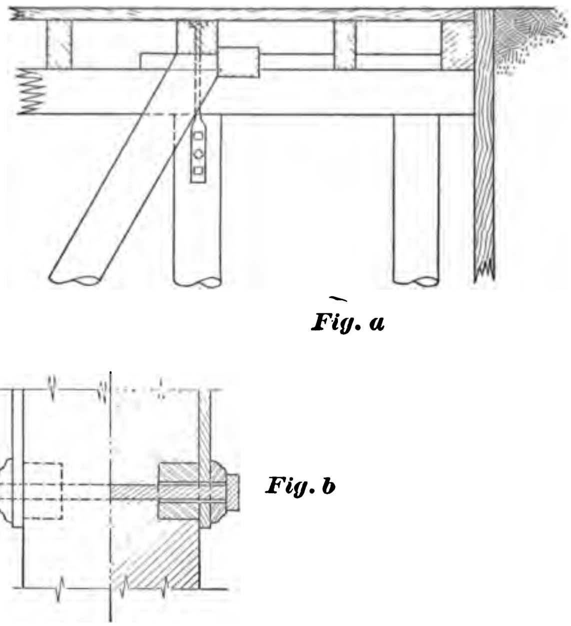


Fig. 43.—Spur pile detail.

bulkheads, in so far as the vertical forces are concerned, is the capping of the spur piles with a timber running across the bent cap and called the "spur cap," which transmits the upthrust to one of the plumb bearing piles of the bent, through a pair of strap bolts, Fig. 43. Even here, it frequently happens that the strap bolts themselves and their fastening to the bearing pile is not given sufficient attention. In the first place, if the reaction is to be transmitted to the plumb pile through the tension in two bolts, one on each side of the pile (as is generally required), the spur cap must

be continuous over spur pile and bent cap, breaking joint somewhere between bents. In the second place, the bolts must be everywhere of sufficient net section to take the tension, and, finally, the attachment to the bearing pile must be adequate in shear and bearing both in the metal and timber. It is the latter, the bearing of the bolts in the holes through the pile, that proves most troublesome.

Referring to the assumed problem, the stress in each strap bolt is 10,700 pounds, requiring 10.7 sq. in. of end grain bearing for a unit value of 1,000 pounds per sq. in. Using 7/8 in. bolts through the pile from strap to strap, this means that three would be required, since it is hardly safe to assume that a length of hole more than four times the diameter of the bolt is effective in taking the bearing because of the bending of the bolt. It is next to impossible, however, to bore three holes through a 14 in. pile such that they will be opposite the bolt holes in each strap on each side. Lag screws may be substituted, but are not wholly satisfactory. A scheme devised by the author employs a single heavy bolt, about 1¼ in. in diameter, and two cast iron spools to furnish the required bearing surface, one at each side, Fig. 43, page 138. The spools are cast with a slight taper and driven snugly into holes bored by a 3¼ in. auger to the depth required. The pile surface under the straps must be freed of bark before placing them. This makes a positive and inexpensive fastening, easily installed.

Pressures on Wet Dikes.—In the design of dikes for enclosing a submerged basin, there are three conditions of loading to be considered, although all three may not necessarily obtain in all dikes, not in all portions of the length of one specific dike.

They are as follows:

Case I.—The pressure exerted by the dredged material, when in a saturated or semi-fluid condition, while the hydraulic filling is still in progress.

Case II.—The hydrostatic pressure of a head of contained water alone, which, having dropped its suspended

matter, is still retained within the basin up to the elevation of the crest of the waste-weir.

Case III.—The pressure of the ultimate loading, when the completely filled basin, having drained and dried out, is subject to the weight of surcharge or of extraneous dead or live loads.

In all three cases, the internal pressure is partly counteracted by the external hydrostatic pressure, the critical loading obtaining when the latter is a minimum at the time of extreme low water.

In the first case, the controlling factors are the nature of the material dredged, the size and shape of the basin and the manner and rate of filling. Usually, in the process of filling the basin, the discharge pipe-line is lengthened by the addition of pipe sections only as the fill at its mouth is brought up to final grade, resulting, after a time, in a basin filled to grade and dry in the vicinity of the point of initial discharge, from which the surface of the fill slopes gently down beneath the contained water to the original bottom in the remoter portions of the basin, where simply a head of water exists from the original bottom of the basin to the elevation of the height of the crest at the sluice. As the pumping continues, the inclined surface of the fill progresses toward the sluice, tending constantly to decrease the surface area of the contained water and thus necessitating raising the elevation of the water by the placing of additional weir boards in the sluice-box in order that the submerged or impounding area may remain sufficiently large to fulfill its function of precipitation necessary to a reasonably clear effluent. If the dredgings consist entirely of alluvial silt or river mud, this surface slope will be very flat and a large impounding area required. If the material be of uniformly heavy material, the slope will be sharper, permitting a smaller basin. Finally, if the pumpings be a mixture of mud or silt and some heavier material such as coarse sand, the effect of the hydraulic handling will be to segregate the two, the sand being deposited quickly near the mouth of the discharge pipe, so that only

the more remote portions of the dike will receive the greater thrust of mud alone. Even if mud be the sole element of the pumpings, the area of the basin may be so great and the rate of filling so slow that, before the fill attains its final elevation, the earlier pumpings near the bottom will have had opportunity to compact or set to a certain extent, acquiring an appreciable angle of repose and lessening the pressure. More especially will this be true if the basin be drained at frequent intervals.

The greatest possible pressure of the first condition of loading is that resulting from a filling of what is virtually liquid mud. River mud submerged or completely saturated has an angle of repose of zero, so that it exerts a fluid pressure which is much greater than that of water because of the greater weight of the liquid. Whether or not the dike will be subjected to a total head of liquid mud, the engineer must predetermine from a study of the foregoing elements.

The pressure of Case II can be the critical loading only when the pumped material is of such heavy nature as to deposit rapidly and exert a horizontal thrust less than that of the head of contained water. In such case, the maximum head will obtain when the basin is in an advanced stage of completion and the weir has been raised to or nearly to its full height.

The loading of Case III presupposes the subsequent use of the fill for commercial purposes, entailing the placing of heavy, quiet or moving loads upon its surface close to the dike.

The pressures resulting from the three conditions of loading will now be investigated.

Case I.—Let us assume a dike built in 8 feet of water and rising 10 feet above the surface, subjected to a loading of liquid mud. We then have a retainer separating two fluids of different weights and heads, the mud emulsion on one side weighing 100 lbs. per cu. ft. with an 18 ft. head, and water on the outside weighing 60 lbs. per cu. ft. with a head of 8 ft., Fig. 44.

in which

P_m = the resultant internal mud pressure per ft. of dike.

P_w = the resultant external water pressure per ft. of dike.

Then $P_m = \frac{1}{2} \times 100 \times \overline{18}^2 = 16{,}200$ lbs., acting at a distance $\frac{18}{3}$ or 6 ft., above the bottom.

$P_w = \frac{1}{2} \times 60 \times 8^2 = 1{,}920$ lbs., acting at a distance $\frac{8}{3} = 2'\text{-}8''$ above the bottom.

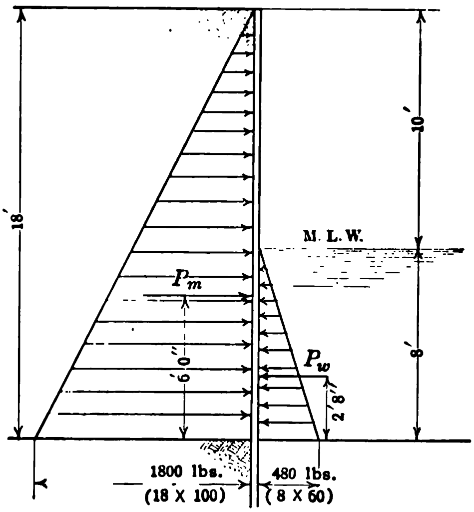


FIG. 44.—Dike loading—Case I.

Case II. Now suppose that the critical loading of the same dike be that of the second condition, i.e., hydrostatic pressure on both sides. The resultant internal pressure per foot of dike becomes $\frac{1}{2} \times 60 \times \overline{18}^2 = 9{,}720$ lbs., the external pressure and the point of application of each remaining the same as in Case I.

Case III.—Finally, let us apply the third or ultimate condition of loading to the dike, assuming that the filling be a mixture of gravel, sand and clay and that the live load surcharge equals 600 lbs. per sq. ft. The table, page 143,

taken from the American Civil Engineers' Hand Book (Merriman), gives the weight, slope and angle of repose of various materials both as loose earth in air and as excavated material dumped into water. Using the following notation:

	Loose Earth in Air			Excavated Materials Dumped into Water		
Kind of Material	Slope of Repose	Angle of Repose	Weight lbs. per cu. ft.	Slope of Repose	Angle of Repose	Weight lbs. per cu. ft.
Clean sand........	1.5 to 1	33°—41′	90	2 to 1	26°—34′	60
Sand and clay.....	1.33 to 1	36°—53′	100	3 to 1	18°—26′	65
Clay—dry........	1.33 to 1	36°—53′	100	3½ to 1	15°—57′	80
Clay—(damp) (plastic)....	2 to 1	26°—34′	100			
Clean gravel......	1.33 to 1	36°—53′	100	2 to 1	26°—34′	60
Gravel and clay...	1.33 to 1	36°—53′	100	3 to 1	18°—26′	65
Gravel, sand and clay............	1.33 to 1	36°—53′	100	3 to 1	18°—26′	65
Soil..............	1.33 to 1	36°—53′	100	3½ to 1	15°—57′	70
Soft rotten rock..	1.33 to 1	36°—53′	110	1 to 1	45°—0′	65
Rip rap...........				1 to 1	45°—0′	65
River mud........				∝ to 1	0—0	90

W_a = weight per cubic foot in air
W_w = weight per cubic foot in water
ϕ_a = angle of repose in air
ϕ_w = angle of repose in water

The quantities for a mixture of gravel, sand and clay are:

W_a = 100 lbs.
W_w = 65 lbs.
$\phi_a = 36°53'$
$\phi_w = 18°26'$

The most workable formula for earth pressure, P, per foot of dike and one whose degree of accuracy is consistent with that of the other factors of our problem is

$$P = \tfrac{1}{2}\, wh^2 \tan^2 (45° - \tfrac{1}{2}\phi)$$

which assumes that, were the dike to be removed, the backing would fail by parting along the plane *ac*, Fig. 45*a*, called the plane of rupture, and making an angle with the vertical of $45° - \tfrac{1}{2}\phi$, so that the horizontal thrust against

the dike is caused by the tendency of the wedge *abc* to slide upon the plane *ac*, and is the horizontal component of a force paralleling the plane of rupture, the vertical component of which is the weight of the sliding wedge *abc*.

For one horizontal foot of wall, the quantities involved are:

Area of sliding wedge *abc* $= \frac{h}{2} \times h \tan (45° - \frac{1}{2}\phi)$

$= \frac{1}{2}h^2 \tan (45° - \frac{1}{2}\phi)$

Weight, *W*, of sliding wedge *abc* $= \frac{1}{2}wh^2 tan\ (45° - \frac{1}{2}\phi)$

Horizontal thrust, *P*, $= W \tan (45° - \frac{1}{2}\phi) = \frac{1}{2}wh^2 tan^2\ (45° - \frac{1}{2}\phi)$

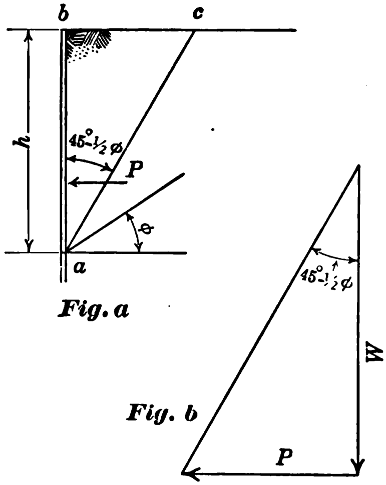


FIG. 45.—The sliding wedge.

P may be found graphically, Fig. 45*b*, by laying off to scale on a vertical line the weight, *W*, of the sliding wedge and the angle of rupture, $45° - \frac{1}{2}\phi$, then closing the triangle by a horizontal line, the length of which equals the thrust, P.

In the problem assumed, $45° - \frac{1}{2}\phi_a = 45° - \frac{(36°\ 53')}{2} = 26°34'$ and $45° - \frac{1}{2}\phi_w = 45° - \frac{(18°26')}{2} = 35°47'$. The conditions then are as shown in Fig. 46.

The weight of the sliding wedge is made up of three parts:

(1) the area *abc* in sq. ft. × W_w
(2) the area *bdefc* in sq. ft. × W_a
(3) the length *df* in ft. × 600.

and, if the figure is drawn accurately with scale and protractor, the areas may be found from scaled dimensions.

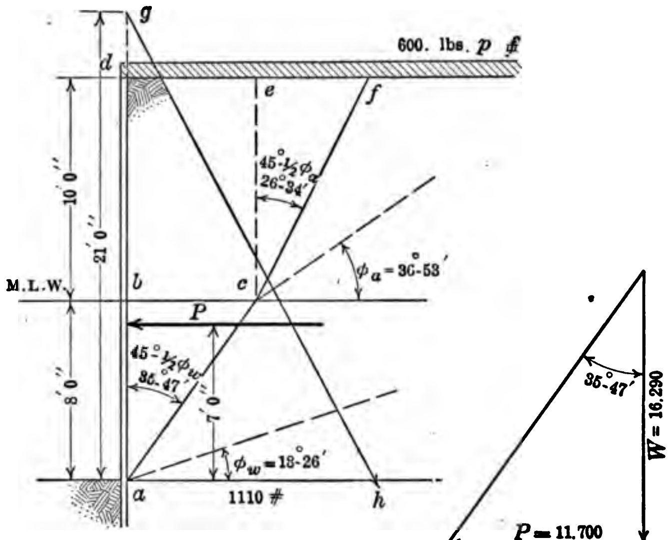


Fig. a *Fig. b*

FIG. 46.—Dike loading—CASE III.

The total weight of the composite sliding wedge and the angle of rupture of the lowest stratum determine the magnitude of the horizontal thrust. The total weight is

Submerged stratum	*abc*	= 1510 lbs.
Dry stratum	*bdefc*	= 8300 lbs.
Live load	*df* × 600	= 6480 lbs.
	Total	16,290 lbs.

Then, graphically, as before,

$$P = 11{,}700 \text{ lbs.}$$

In this instance, the solution yields the net thrust, as the water pressure has already in effect been deducted by

reason of the fact that the quantities used for the submerged stratum were submerged quantities. The pressure to be resisted by the wall is, therefore, 11,700 lbs.

The formulæ will of course yield the same answer without graphical aid.

Design.—In those dikes not of the gravity type, it now remains to ascertain the stresses in the sheet piling and the proportion of the thrust transmitted thereby to the above water structure. The most convenient treatment is by the method of equivalent fluid pressure, i.e. the determination of the weight of a hypothetical fluid which will produce the same thrust P both in magnitude and point of application. Resultant earth pressures act at a point somewhere between one-third and one-half the height of the wall from the bottom. Where the live load surcharge is considerable, the point of application may be safely assumed at 0.4 the height. In our problem, this point will be 0.4×18 or 7.2 feet from the bottom. Call it 7 feet even. Hydrostatic resultant pressures, however, act at one-third of the height. The head, therefore, of the so-called equivalent fluid will, in this case, be $3 \times 7 \times$ or 21 feet, and the resultant pressure $= \frac{wh^2}{2} = \frac{w \times 21^2}{2} = 220.5w$. Equating this to the above value of P and solving for w, we find that a fluid weighing 53 pounds per cubic foot will exert an equivalent thrust. The unit pressure at the base of the wall $= wh = 53 \times 21 = 1110$ lbs. Again, in the Fig. 46, lay this off to scale and draw the triangle of fluid pressures, *agh*, from which the unit pressure at any point of the height may be scaled and the stresses in the structure analyzed. In the case of the mud fence, the first step from this point will be the determination of the proportion of the thrust carried by the tie rods and spur piles, whence, knowing this reaction, the bending moment in the sheet piling may be found.

As a more complete illustration of the problem subsequent to the evolution of the pressure triangle of the equivalent fluid, let us discuss the case of the relieving-platform, sheet-pile bulkhead, Fig. 47.

The sheeting is a vertical beam fixed at the lower end at *A* and supported at the top, *B*. The point of fixture, *A*,

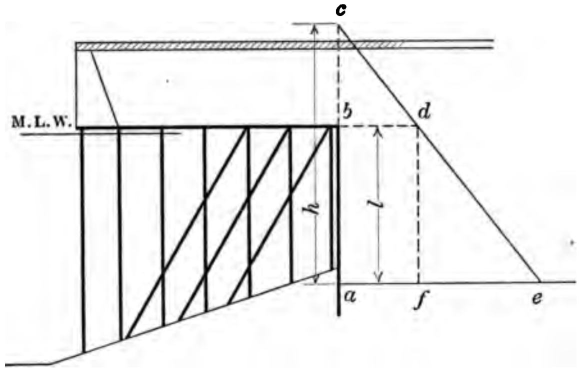


FIG. 47.—Platform bulkhead.

will be at or a short distance below the mud line, depending upon the resistant qualities of the material comprising the

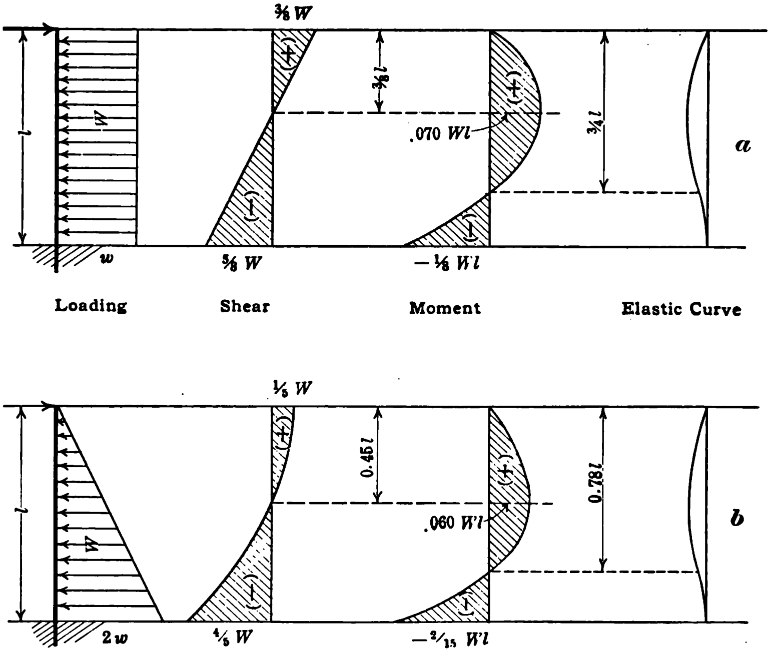


FIG. 48.—Shear and moment in sheet piling.

bottom. For the mixture of gravel, sand and clay, we will assume a value of 2 feet. The beam *AB* is resisting the

trapezoid of pressures *abde*, and the problem is to find the reactions at A and B and the bending moment in the sheeting. To this end, consider the beam loading in two parts; 1st, the uniform load, *bdfa*, and, *2nd*, the uniformly varying load 0 to *fc* pictured by the triangle *def*, and ascertain, independently, the end reactions, the moments and shear in the beam due to each load. Then by combining the two, the critical stresses in the sheeting may be found. Fig. 48*a*, gives the diagrams for the uniform load, *abdf*, and Fig. 48*b*, for the variable load, *def*.[1]

[1] Mechanics of a Beam, of length l, fixed at one end and supported at the other, carrying a total load, wl, varying uniformly from zero at the supported end to $2w$ (twice the average load per foot, w) at the fixed end.

If R_1 = the reaction at the left or supported end, the bending moment, M_x, at any section, distant x from R_1, is

$$M_x = R_1x - \frac{wx^3}{3l} \tag{1}$$

The equation of the elastic curve, using the conventional notation, is

$$EI\frac{dy^2}{dx^2} = M \tag{2}$$

$$\text{whence } EI\frac{dy^2}{dx^2} = R_1x - \frac{wx^3}{3l} \tag{3}$$

$$\text{Integrating (3)—}EI\frac{dy}{dx} = R_1\frac{x^2}{2} - \frac{wx^4}{12l} + C_1 \tag{4}$$

$$\text{Integrating (4)—}EIy = R_1\frac{x^3}{6} - \frac{wx^5}{60l} + C_1x + C_2$$

Since $x = 0$ when $y = 0$, the constant $C_2 = 0$.

and when $x = l$, $\frac{dy}{dx} = 0$. $\therefore$ the constant $C_1 = \frac{wl^3}{12} - \frac{R_1l^2}{2}$

$$\therefore EIy = \frac{R_1x^3}{6} - \frac{wx^5}{60l} + \frac{wl^3x}{12} - \frac{R_1l^2x}{2}$$

$$60\,EIy = 10R_1(x^3 - 3l^2x) - w\left(\frac{x^5}{l} - 5l^3x\right) \tag{5}$$

In (5) when $x = l$, $y = 0$.

$$\text{whence } R_1 = \frac{wl}{5} \tag{6}$$

$$\text{Substituting (6) in (1) } M = \frac{wlx}{5} - \frac{wx^3}{3l} \tag{7}$$

$$\frac{dM}{dx} = \frac{wl}{5} - \frac{wx^2}{l} = 0$$

$\therefore$ Max. positive moment occurs when $x = \frac{l}{\sqrt{5}} = 0.447\,l$ (8)

Substituting (8) in (7), max. pos. $M = +\,0.0596\,wl^2$

Max. negative moment ($x = l$ in (7)) $M = -\frac{2}{15}wl^2$

Point of inflection ($M = 0$ in (7)) is distant $0.775l$ from R_1

Bearing in mind, then, that the W of the first condition, which we will call W_1, equals $bd = af$, and the W of the second, called W_2, equals the average unit load, or $\frac{1}{2}fc$, the combined quantities for the total load $abdef$ are:

$$\text{Reaction at } B \quad = \frac{3}{8} W_1 l + \frac{1}{5} W_2 l$$

$$\text{Reaction at } A \quad = \frac{5}{8} W_1 l + \frac{4}{5} W_2 l$$

$$\text{Max. neg. } B.\ M. = \frac{1}{8} W_1 l^2 + \frac{2}{15} W_2 l^2$$

$$\text{Max. pos. } B.\ M. = \frac{9}{128} W_1 l^2 + 0.06 W_2 l^2$$

the last being not absolutely true, due to the fact that the point of max. pos. *B. M.* is not coincident in the two cases. However, it is sufficiently accurate to be consistent with the other assumptions, and the error is on the side of safety.

The total pressure resisted by the bulkhead structure is the sum of the reaction at B as above, plus the triangle bcd. Whereas the assumption that the point of application of the resultant pressure, for the usual average live load surcharge, is 0.4 of the height from the base is sufficiently accurate for the design of the structures cited, for the larger sea walls, an investigation of the location of that point becomes necessary. Such a discussion, however, is neither commensurate with the scope of this book, nor apropos of our subject title. Mr. S. W. Hoag, in the Proceedings of the Municipal Engineers of the City of New York, 1905, describes in detail the two methods of pressure calculation used by the Department of Docks in New York. The more recent of the two reduces the several component substances of the sliding wedge to a single homogeneous material, that at the base of the wall, whose plane of rupture determines the direction of the pressure. The true centre of gravity of the sliding wedge then is the centre of gravity of this reduced polygonal figure, and the point at which a line drawn through it parallel to the plane of rupture interprets the perpendicular at the back of the wall is the point of application of the horizontal thrust.

Sluiceways.—The structure through which the pumped water escapes from the impounding basin is called variously the sluiceway, sluicebox, sluice or waste-weir. The principal parts of a complete sluice are, first, the box proper, consisting of floor and sides to retain the dike material; second, one or more sheet pile cut-off walls to prevent the percolation of water (and resultant scour) through the dike under and alongside the sluice-box proper; third, the weir itself, built up of a series of planks, set loosely in vertical grooves so that the elevation of the crest of the weir may be raised from time to time by placing additional weir boards as the filling progresses, or lowered to drain the basin; fourth, the tide gates, which are, in effect, large flap valves, opening in the direction of the effluent and preventing the back flow into the basin of outside water under heads created by tides, freshets, or other causes; fifth, a walkway across the sluice for the convenience of the bank patrol and to facilitate the addition or removal of weir boards. While the details of design vary materially with the various types of dike in which the sluice is built, the above features must all be taken care of. Fig. 49, page 151, shows the type of sluice used for earth embankments in connection with the dredging appurtenant to the construction of the Hog Island Shipyard.

The argument used for the determination of pressure against the dike is applicable also to the sluice. In very soft material, it may be necessary to found the structure upon piles. Revetment work of sand bags or rip rap upon the adjacent slopes may be required in some instances. A sluiceway built through a crib or mud-fence dike may require an outboard apron to prevent back scour.

The elevation of the floor of the sluice will be such that the basin can be drained to the minimum desired level. The requisite width of the box, or length of the weir, depends upon the number and capacity of the dredges discharging into the basin. It is desirable that the head of water on the weir crest be not greater than about 6 to 8 inches, in order that the disturbing influences of high

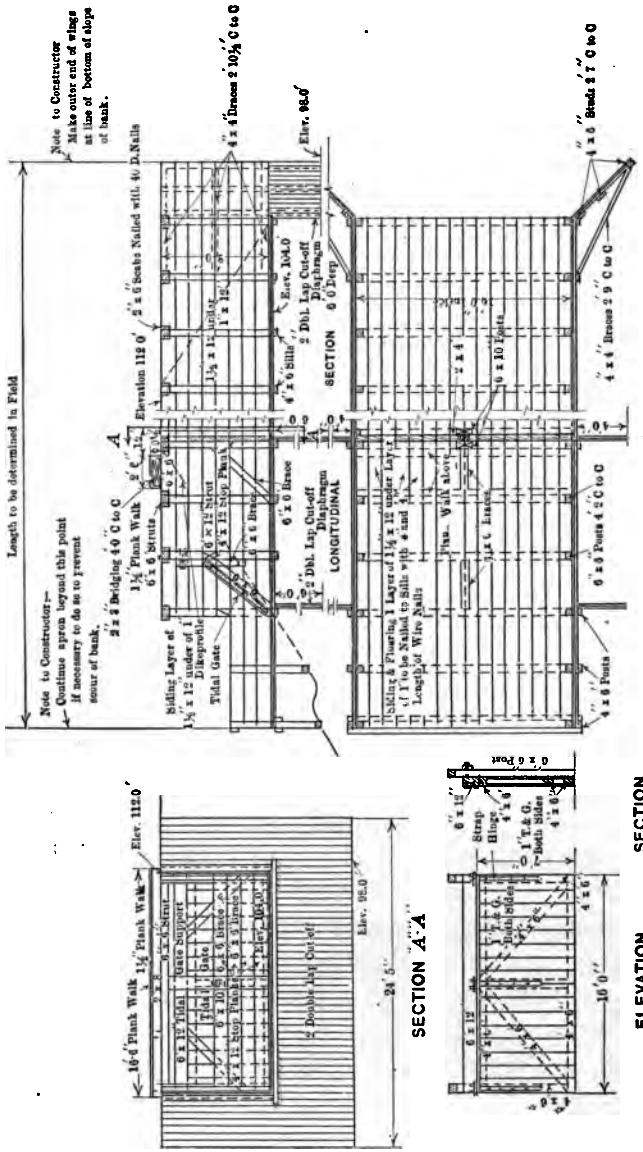


FIG. 49.—Sluice details.

velocity and scour be reduced to a minimum. Thus, the customary width of sluices is about as follows:

12 to 16 feet for one 20 inch dredge or equivalent
30 feet for two 20 inch dredges or equivalent
40 feet for three 20 inch dredges or equivalent

Let us investigate a sluice designed to take the output of one 20 inch machine with an average discharge through the length of line used of 22.0 cu. ft. per second. Francis' weir formula

$$Q = 3.33\, bH^{3/2}$$

gives results sufficiently close for our purpose, where

Q = the discharge in second feet = 22.0
b = length of crest = width of sluice
H = head above the crest measured some distance back from the crest.

Then, for the maximum condition of H = 8 in.

$$b = \frac{Q}{3.33 \times H^{3/2}}$$

$$b = \frac{22.0}{3.33 \times (0.67)^{3/2}}$$

from which, b = 12 ft. (approx.)

Pipe Lines.—The shore pipe is most conveniently laid upon the surface of the ground, but the necessity often arises for the depression of the pipe under roadway and track crossings and for the elevation of the line upon trestles in crossing swamp land, or submerged flats on which the water is too shallow to float pontoons. Such depression generally requires no special structure, as the usual pipe will stand up under the load if at least 9 inches below the base of rail and if the two adjacent ties are spread to distribute the load to either side. Pipe trestles over water are generally built by driving two-pile bents about 12 feet on centres, with the piles from 6 to 8 feet apart in the bents, and clamping the two with one or two horizontal members of 3 × 12 or 4 × 12, which support the pipe. As a rule

no transverse or longitudinal bracing is necessary except in the last 3 to 6 bents and in the ball joint platform, where the pull exerted by the pontoon line must be taken care of. For the same reason, a short stretch of the shore line at the point of connection of shore and pontoon lines is tied together with chain or cable.

FIG. 50.—Pipe lines on pile trestle.

For maximum efficiency, the land pipe line should be laid out with minimum curvature, horizontally and vertically, and, especially, should abrupt changes in direction be avoided.

The location and length of pipe trestles must generally be such as to permit the dredge to reach all parts of the zone ascribed to her without an impracticable length or curvature of the pontoon lines. Machines, unless built for a special purpose, are seldom equipped with more than 1200 feet of pontoon line.

CHAPTER XI

OPERATING

Organization.—The usual method of performing a dredging project involves a dual organization, the dredging contractor's and that of the individual, corporation or governmental department for whom the work is being done. The exceptions are the operation of dredges by governments and by owners upon their own work. We will not attempt a discussion of the organization requirements of the contractor. They will depend upon the size of his plant, its distribution and the extent of his yard facilities for plant construction and repair.

The organization necessary to handle the job for the party having the work done consists of inspectors, stationed upon the dredges, a superintendent and a small field office force to take care of accounts, records and statistics. On machines working 24 hours per day, it will generally be necessary to place two inspectors, one taking the day and the other the night shift. If the payment for dredgings is based upon place measurement, the full or partial services of a hydrographer's force will be required, comprising one or more survey parties, a small office for recording and plotting and an engineer in charge. Their duties will include all surveys and all the field engineering appurtenant to the dredging. Direct pumping into impounding basins may require 24 hours of bank patrol in two or three shifts of so-called dike-men, in numbers sufficient to take care of ordinary dike maintenance. If the contract is such that the contractor's responsibility terminates with his pontoon line, a gang of men is needed to handle the shore pipe lines. Whatever the magnitude of the operation justifies, let it be borne in mind that the key to successful and efficient organization is clear definition of duty and responsibility.

Cut and Range Layout.—In order that dredges may work to the best advantage and make a uniform bottom, it is customary, where practicable, to divide the area to be dredged into a series of parallel bands or belts, called "cuts," defined by ranges marked by flags or targets set up on shore or on stakes or piles in the water. Buoys are sometimes used for range markings, but are objectionable in their variation of position within the radius of their mooring cables. The dredge operator, by lining himself

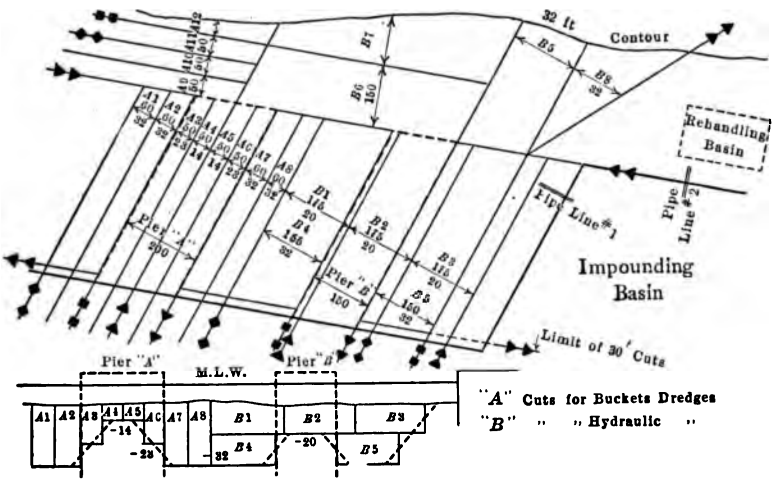


FIG. 51.—Cut and range layout.

in with the targets, maintains his position in the cut between a pair of ranges. The cuts are designated by some convenient notation, numbers or letters or a combination of the two. A record of the area dredged can then readily be kept by having the inspector report the cut in which he is working and the distance advanced in that cut daily. A plan of the cut layout is therefore very useful both to field and office forces. The information shown on it should embody not merely the lines and widths of the cuts, but also the range targets, the specified cross section and the relative position of the cuts thereto. Such a plan is shown in Fig. 51, page 155. It is not necessary for grapples and dippers to have a [illegible] each side of each cut. Every

other cut is enough, as the runner can line in with his port side on one and his starboard on the other.

There are several practical considerations that are pertinent factors in drawing up a workabe cut layout. In the first place, the width of cut adopted must be suitable to the machine used. Grapple dredges, loading scows, can make a cut from 10 to 20 feet wider than their beam, because, while they are limited on one side by the scow, they can swing on the other somewhat beyond the line of the hull produced. Thus a dredge of 40 ft. beam, swinging a bucket of from 6 to 10 yards capacity on a boom of the usual length for loading scows, can dredge a width of about 50 to 60 feet without lateral movement. The same is true of dipper machines in shoal digging, but when dredging to more than medium depths, the side reach of the dipper is decreased, due to the increased length of dipper stick required to reach the bottom, so that the width of cut may be limited even to the width of the hull. Hydraulic dredges of the swinging-ladder type will usually cut a swath approximately equal to or perhaps slightly greater than the width of their hulls, i.e. about 40 to 50 feet. Hydraulic machines that swing about a stern spud must work in a cut about 150 to 200 feet wide, for the reason that the distance which they step ahead by alternating the spuds is determined by the length of the arc traversed. In light digging, therefore (i.e. where the depth of cut is small) the minimum width of cut is greater than in heavy cutting, because the distance advanced at each step must be greater in the former to maintain the pump feed at its maximum capacity.

Secondly, it is preferable that the direction of the cuts be parallel to the current. Dredging at an angle with the direction of flow, or "cross tide," involves inconvenience and at times real difficulty in overcoming the resistance of the current to holding and advancing the dredge in the cut.

When the original depth of water is too little to float scows, it becomes necessary, if the expense of pilot machines is to be avoided, to dredge always on the edge of the bank

and always in that direction which places the scow on the deep water side of the dredge, and the cut layout must be planned accordingly.

The marginal cut must be so placed relative to the side slope that the resulting bottom width of channel from toe to toe of banks shall be as specified. In other words, the cut will extend part way up on the slope so that, after it has been dredged to the full depth and width, the sloughing in of the bank to its natural angle of repose will place the toe of the slope in the location specified.

Finally, the locations of pipe trestles and the cuts for hydraulic machines shall be coordinated to give pontoon lines of workable and economic curvature and length.

Hydrography.—The field engineering appurtenant to the operation of a dredging project comprises the following:

1. The cut layout having been planned, it is the duty of the hydrographer to compute the position of the range targets with respect to known stations, to locate them in the field, set them up, and maintain them. To avoid possible confusion where the number of ranges is large, it is desirable to employ distinguishing symbols for the targets. A convenient method is the use of timber frames built in various forms, such as shown in Fig. 49, elevated upon poles. Flags of different colors are sometimes used.

2. Tide gauges must be set and maintained at points from which they can be read by the dredge operators. They are simply vertical planks graduated in feet with the zero at the datum elevation.

3. If the material is removed hydraulically, involving periodical estimates of the amount dredged by measurement in place in the cut, soundings are taken over the area before and after dredging, and plotted in the office upon one tracing, distinguishing between the two surveys by underlining each individual sounding of one set, or by some similar notation. The volume is then computed as described under "Preliminary E[illegible]ering."

4. Shoals, [illegible] after dr[illegible] are located by sounding or "sweep[illegible] charte[illegible] information of the

Captain and inspector of the dredge assigned to their removal, which is then termed a "lumping" machine. "Sweeping" may be defined as the operation of passing over the dredged area a submerged straight edge, suspended horizontally at the specified depth, to detect the presence of shoals or lumps protruding above that depth. Steel rails or structural shapes are used for the purpose, hung in such a way that the men on the float above are immediately aware of any interruption to smooth progress. With a sweep as long as 60 feet, and the float propelled by a motor boat, a considerable area can be covered in a short time. The obstructions so found are investigated by lead line or diver or both as the necessity requires and are located by instrument or range intersection and charted for removal.

5. The quantity of overdepth dredging in excess of the allowance is computed from after dredging soundings. The survey establishing the shoals may serve this purpose also.

6. Where a great many dredges are working in a confined space in close proximity to one another, the difficulty of isolating the area covered by each machine becomes acute, more especially in the case of hydraulic machines working for place measurement compensation. Under these conditions, it is helpful to plot the dredge locations at intervals of one or two days, as found by angular intersection with sextant or transit, dating the successive positions on the map. In locating swinging hydraulic machines, which are constantly changing position, it is enough simply to locate the pivotal spud, which can then be plotted on the chart as a point or small circle, with an arrow pointing from it in the direction of the advance, and drawn to scale equal in length to the dredge from spud to cutter head.

7. Contracts for hydraulic plant sometimes provide that payment is in some way dependent upon the length of pipe line in use, in which case it is advisable that the inspectors' reported lengths be checked occasionally by actual tape-line measurement.

Inspection.—The inspector is the dredge time keeper and material clerk. Upon him, the office depends for all in-

formation necessary for complete statistics and determination of amount of compensation.

Let us first consider the duties of an inspector on a grapple or dipper dredge. To facilitate and standardize the data furnished by him, he is provided with three sets of blank forms and a log book. One form is the bill of lading, bound in books of about 100 each, so that the stubs may be retained therein for record in their proper sequence. A bill of lading is made out by the inspector for each scow of material shipped by the dredge and numbered in chronological order. A typical bill is shown in Fig. 52. On the reverse side of each bill is a diagram of the plan of the scow, upon which the inspector designates the loading condition of each pocket, whether "F" for full, "E" for empty, or the amount of cut for pockets partially loaded. The inspector is furnished

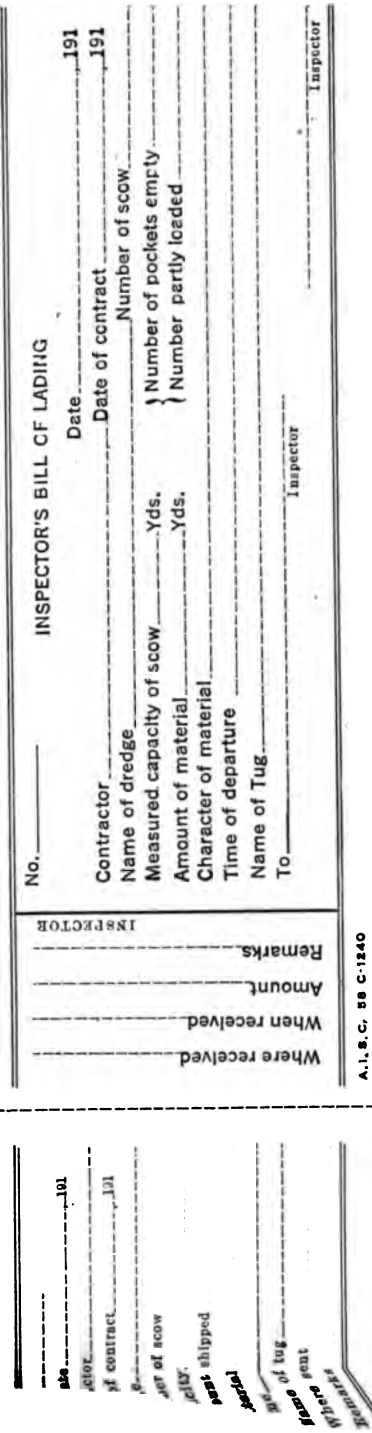


Fig. 52.—Bill of lading.

with data as to the capacity of each scow, of each pocket and the deduction for one-tenth foot of coaming for each pocket, from which he is able to estimate the amount shipped, whether a full or partial load.

The bill of lading goes with the scow to the place of discharge, whether free dump or rehandling basin. If the former, the inspector on the tug fills in the amount dumped and place of dumping, deducting any material that is lost in transit. He then signs and returns the bill to his employer. If the material is to be pumped ashore, the inspector on the rehandling machine performs the same function since, then, there is no necessity for an inspector on the tow. At the end of each month the bills and stubs afford a complete record of the yardage shipped and where dumped.

The second printed form is the daily report, containing, in addition to the numbers and contents of the scows loaded, a detailed log of the events of the day as well as a summary of the depth information, all as shown on the specimen blank, Fig. 53, page 161.

The third sheet is intended as a convenience to the inspector in recording and tabulating the results of his before and after dredging soundings.

The log book is simply a duplicate record of the information submitted on the daily report.

The contractor, too, keeps his records, so that there is an abundance of checking data available, leaving little opportunity for paucity of evidence in the event of dispute.

The stationary hydraulic dredge inspector has a somewhat different class of work. He has no bills of lading since there are no scows. His sounding sheet is the same, but the daily report is quite different—Fig. 54, page 162. A study of it clearly defines his duties. His yardage reports are merely approximations, because they are computed from his own soundings without instrument location, the pay quantities being based on engineers' surveys. The nature of the material he ascertains by periodical visits to the impounding basin.

A.I.S.C. C-600-58-2M

Daily Report of Dredge__________

located at__________ for__________, 191

MATERIAL	SCOWS			CUBIC YARDS		TUG	DELAYS	Dumped At	REMARKS
	Began Loading	Finished Loading	No. of Scow	Capacity of Scow	Amount Shipped				
									Commenced Work:
									Stopped Work: Hours Worked:
									Hours Idle: Hours Overtime:

TOTAL TODAY__________

TOTAL FOR MONTH__________

TOTAL TO DATE__________

__________ Inspector

Specification depth__________feet
Average depth before Dredging__________feet
Maximum depth after Dredging__________feet
Minimum depth after Dredging__________feet
Average depth afte Dredging__________feet
Length of cut__________feet
Width of cut__________feet

FIG. 53.—Daily report—grapple or dipper dredge.

A.I.S.C. 68-C-1165

American International Shipbuilding Corporation

Daily Report of Hydraulic Dredge ______________________________

Contract with __________________________ **dated** __________________ **191**

Dredging at ______________________________ **on** __________________ **191**

Cut No.______ Station No.__________ Width of cut __________ feet

Total advance in cut to-day________________ feet. Depth of cut.__________________ feet

Approximate amount dredged________________ cubic yards.

REMARKS

(Describe kind of material, where deposited and note any information necessary to a clear understanding of the work.)

____

____

____

____

____

____

____

____

________________________ Dredge Captain ________________________ Inspector

FIG. 54a.—Daily report—hydraulic dredge.

Distribution of Effective Working Time	Distribution of Time Lost
Pumping ______ Hrs. ___ Min.	Repairs to Dredge ______ Hrs. ___ Min.
Handling Pipe Line ______ Hrs. ___ Min.	Repairs to Floating Pipe Line ___ Hrs. ___ Min.
Handling Lines and Anchors ___ Hrs. ___ Min.	Repairs to Banks or Sluice ______ Hrs. ___ Min.
Moving Dredge ______ Hrs. ___ Min.	Weather ______ Hrs. ___ Min.
______ Hrs. ___ Min.	Coaling ______ Hrs. ___ Min.
______ Hrs. ___ Min.	______ Hrs. ___ Min.
______ Hrs. ___ Min.	______ Hrs. ___ Min.
______ Hrs. ___ Min.	______ Hrs. ___ Min.
______ Hrs. ___ Min.	______ Hrs. ___ Min.
______ Hrs. ___ Min.	______ Hrs. ___ Min.
______ Hrs. ___ Min.	______ Hrs. ___ Min.
______ Hrs. ___ Min.	______ Hrs. ___ Min.
Total Time Worked ______ Hrs. ___ Min.	Total Time Lost ______ Hrs. ___ Min.

NOTE: 24 hours per day must be accounted for.

PIPE LINES

Floating Pipe Line	Land Pipe Line
______ Feet In Use 12.01 A.M.	______ Feet In Use 12.01 A.M.
______	______
______	______
______	______
______	______
______	______

MISCELLANEOUS INFORMATION

Weather ______ Coal Used ______ Tons ______

______

______

______

______

______

______

(Space below this line not to be filled in by inspector)

Time Worked ______ Hours ___ Min.

Time Lost Chargeable to A. I. S. C. at Full Rate ______ Hours ___ Min.

Time Lost Chargeable to A. I. S. C. at Half Rate ______ Hours ___ Min.

Time to be Paid For ______ Hours ___ Min.

Time Lost Chargeable to Contractor ______ Hours ___ Min.

Total Time Accounted For ______ Hours ___ Min.

Average Length of Pipe Line In Use During Day ______ Feet

FIG. 54b.—Reverse side of report of FIG. 54a.

The inspector's further duties, whether he be a bucket or hydraulic man, comprise reporting promptly to the office the absence of range targets and tide gauges and any deviations from the specifications or contract.

It is apparent that the reported information must be particularly accurate and in greater detail for machines working under contracts of lease, as the time element then determines the amount of compensation.

FIG. 55.—Spoil bank—20 inch dredge. *(Courtesy of Morris Machine Works.)*

Basin Regulation.—A hydraulic fill builds up most rapidly near the mouth of the discharge pipe, sloping away toward the dikes and sluice. It is impossible to make a fill in such a way that the finished surface will be a level plane, but is is practicable to approximate this condition if desired by frequent changes in the location of the point of discharge through the extension of the line by adding pipe sections or through shifting the line laterally. The use of a *Y* and gate valves on the fill facilitates both the uniform distribution of the deposit and the addition of pipe without causing the dredge to stop pumping. As the fill rises, it becomes necessary to increase the elevation

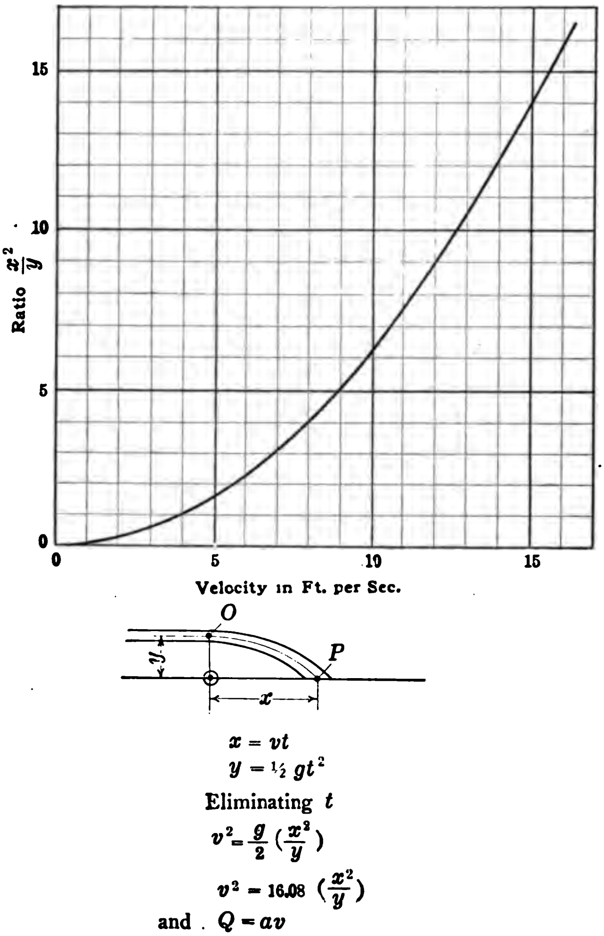
of the crest of the sluice by placing additional weir boards, in order that the quantity of water retained within the basin —or in other words that the impounding area—shall be great enough to allow such quantity of sedimentation therein as to preclude the loss of a large percentage of solid matter by being carried away in suspension in the effluent. It is not that such loss is disadvantageous to the party making the fill (rather is it a benefit as an inexpensive method of disposal of dredgings), but that a rich weir discharge will result in shoaling outside of the sluice or in adjacent waterways and channels, to the detriment of adjoining property owners and the maintenance of nearby channels. For this reason, the War Department has absolute authority to restrict the amount of solid effluent. Samples of the sluice water are taken in jars from time to time and allowed to stand until they clarify and the percentage of solids noted. The addition of a little alum will accelerate the precipitation. The allowable percentage depends upon the conditions. The sluice may be so located as to cause little or no disadvantage from outflowing material or, on the other hand, its location relative to dredged channel may result in serious shoaling therein. Should it become necessary to continue pumping into the basin after the sluice weir has attained its full height and the effluent has become too rich for acceptance, the impounding area may be increased, in effect, by the interposition of baffles between the pipe discharge and the sluice, causing the water to pursue a more devious course to the weir and thereby increasing the opportunity for sedimentation.

It is often helpful to drain the basin occasionally when approaching repletion, allowing the mud to compact or set, thus rendering the effluent more lean and relieving to some extent the pressure on the dikes.

Dike maintenance is, of course, a feature of "operating." The destructive agencies to be guarded against and the methods of protection have been outlined under the heading "Dikes for Impounding Basins."

The quantity of pumpings [illegible]ing a basin may be

approximated by measurements of the rectangular coordinates of the curve of the pipe discharge with respect to the end of the pipe. With the pipe running full and the end section horizontal, measure the vertical and horizontal



$$x = vt$$
$$y = \tfrac{1}{2} gt^2$$

Eliminating t

$$v^2 = \frac{g}{2}\left(\frac{x^2}{y}\right)$$
$$v^2 = 16.08\left(\frac{x^2}{y}\right)$$

and $Q = av$

FIG. 56.—Curve for determining discharge from the coordinates.

distance from any point on the centre of the curve to the centre of the end of the pipe. A photograph will facilitate the measurement, first fixing the point to be measured by placing a batten horizontally in the plane of and a short distance below the pipe. Referring to Fig. 56, page

let X and Y be the coordinates of the point P referred to the origin 0.

If V = velocity in feet per sec.

T = time in secs.

and G = acceleration of gravity in feet per sec. = 32.16

then $X = VT$

and $Y = \frac{1}{2} GT^2$

eliminating T, $V^2 = \frac{G}{2}\left(\frac{X^2}{Y}\right) = 16.08\left(\frac{X^2}{Y}\right)$

FIG. 57.—A powerful discharge; velocity about 18 ft. per second. (*Courtesy of Morris Machine Works.*)

Solve for V, after which the quantity Q in cu. ft. per sec. follows from the formula $Q = AV$ here A = the sectional area of the pipe in sq. ft. The curve of Fig. 56, page 166, plotted from the above formula, gives the velocity directly for any value of the ratio $\left(\frac{X^2}{Y}\right)$.

Progress Keeping. Complete progress information embodies records of three distinct elements, yardage removed, area covered and time distribution, each of which is collected, compiled and presented in some concise form from

which the important facts may quickly be assimilated. The graphical method is easily the most legible and may be employed in all three cases.

The daily output of each dredge, or, if desired, the output of a group of dredges working in one zone as scheduled, is plotted vertically with respect to working days on the horizontal axis, and the resulting curve will show at a glance the fluctuations in performance. A straight horizontal line representing the assumed daily average yield of the dredge, or group of dredges, is drawn to the same axes. The area included below the curve must be at least equal to that below the straight line if the dredge is up to the schedule. On a second set of axes, the accumulated yardage is plotted with reference to working days, showing the total yardage to date at any time. By comparing this curve with a line drawn from the same origin on the same sheet representing the total scheduled yardage to date of any day (which line is called the "bogie") the number of days or cubic yards by which the dredge is behind schedule is obvious. The vertical axis of the same sheet may also be graduated to give the percentage of completion at any time. Additional "bogies" and curves may be drawn for the summarized output of all the dredges on the job, or of all the bucket, or all the hydraulic machines. Such graphs are very helpful in adhering to a dredging schedule.

The record of area covered is best kept on a map showing the cut layout, by coloring the area dredged each day by each machine. Different colors are used for different depths, and the distinction between areas reported dredged and those shown by final survey to be down to depth may conveniently be indicated by cross hatching the former and solidly coloring the latter.

The graphical distribution of time is of value in bringing out for each dredge the percentages of lost time due to various causes, such as lack of plant (waiting for scows or tug-boats), lack of supplies (coal, etc.), repairs, weather, tide, etc. One method divides a rectangle into areas of different colors, each indicative of one class of lost time or

of working time and representing by its relative length the percentage of the total time for the day, or week.

This question of distribution of time and the percentage of lost time due to various causes is obviously of vital interest to the contractor. Dredging operations are characterized by few units of large capacity. When one machine is idle, a big percentage of the work is at a standstill and a large investment becomes unproductive. Thus it is of paramount importance that all the units be kept busy all of the time and, to this end, a thorough study of the lost time, its cause and remedy is imperative.

CHAPTER XII

REMOVAL OF SUB-AQUEOUS ROCK

As has been said, the high-powered ladder dredges are able to remove by direct dredging the softer rock formations. When, however, the rock is harder than lies within the capabilities of these machines, some means must be used to prepare the rock for dredging, comprising the reduction of the strata to relatively smaller pieces. There are two general methods: first, by the use of explosives and, second, by the use of rock-breaking machines. Again, there are two general methods of using explosives: first, by undermining and blasting, and, second, by drilling and blasting from the surface. This last is by far the more popular method in this country, the other having been used to a limited extent only.

The problem then arises as to whether the softer rocks, such as corals, soft limestones and tufas, are more economically removed by large, powerful dredges from in situ without previous blasting, or by smaller, less expensive dredges after first breaking up the rock by blasting or by rock breaking machines. On the one hand, we have the saving effected by the omission of drilling and blasting to offset the increased cost and rapid depreciation of the larger dredging plant over a longer period of time and, on the other, the saving effected by the use of lighter dredging equipment in less destructive material, over a shorter period (because of increased output) to offset the added cost of drilling and blasting. The question apparently is still an open one and will, of course, be influenced by conditions peculiar to each project.

Undermining and Blasting.—The method of rock removal by undermining and blasting consists in the sinking

of vertical shafts, from the bottom of which a series of horizontal galleries are driven, after which charges are placed in drill holes in the remaining supporting and overlying rock and exploded in one operation. In the removal of Flood Rock, New York Harbor, General John Newton sank two shafts, from which he drove a series of galleries 10 feet square at right angles to each other, leaving a roof supported by square columns of rock 15 feet on a side. The roof and columns were drilled, loaded and simultaneously fired after admitting the water. The total cost was $5.88 per cu. yd., of which $3.19 was the cost of the subsequent dredging.

Drilling and Blasting from the Surface.—This method comprises the drilling of a series of vertical holes down into the rock by means of drills mounted on floating hulls, after which the holes are loaded, usually from the deck by means of a charging pipe, and then fired. The holes are drilled at the corners of squares, the sides of which vary with the character of the rock from about 4 to 8 feet. In order that the rock may break to the specified depth, the holes are drilled to several feet below that grade.

From the original humble raft carrying one drill, the drill boat has developed into the modern steel hull mounting as many as five or more traveling drill frames, and equipped with spuds or columns, upon which it is set up on the rock, free from wave motion. These spuds, one at each corner of the hull, are being forced down while the drills are working and the boat is raised above the elevation of normal flotation, in which position it is maintained by the automatic regulation of the steam pressure in each spud engine. The drills are usually of the steam-driven percussion type and are carried on traveling steel towers from which vertical leads extend down over the edge of the hull, forming guides for the drill cylinders. The drill feed and the tower travel are generally power-operated.

In order to prevent the transmission of the barge motion to the drill in waters of wide tidal range, the drill, guides and feed mechanism are mounted upon a steel column in-

stead of the tower. The base of the column rests on the rock and is so attached as to permit the vertical motion of the boat independently of the drill.

The essential requirements of a submarine rock drill are great striking power, quick action, strength and durability.

Some drill barges have been constructed in which the drills operate through a central well in the hull. Others are equipped with pipes for enclosing the drill in passing through the overlying soft strata to keep it free of obstruction.

Rock-Breaking Machines.—In this method, the rock is broken up by the impact of a fulling ram. For many years, Lobnitz & Co., of Renfrew, Scotland, have manufactured machines of this kind. The ram weighs from 6 to 15 tons and has a projectile shaped cutter-head. They are raised from 6 to 15 feet and dropped about four times per minute. The concentrated impact is capable of breaking the hardest rock. After one layer is broken to a depth of several feet, it is removed by dredging and a second layer attacked. The action of the machine is partly to pulverize and partly break the rock.

The machinery for operating the ram, comprising an "A" frame and hoisting engine with friction clutch, is mounted on a barge, held in position by cables from winches on deck. The surface of the rock is attacked with the breaker at intervals of about four feet each way. The limit of penetration (usually about 3 feet) is obtained at each point before going to the next.

The Submarine Company, of New York, manufacture a rock breaker in which a heavy hammer, working inside of a long cylinder suspended from the "A" frame, strikes a short chisel resting on the rock and attached to the lower end of the cylinder in a manner permitting a limited amount of vertical motion. Greater efficiency is claimed because the hammer works in air, the water being excluded by compressed air.

Breakers of the Lobnitz type appear to be the most economical means of preparing hard rock for dredging, when the rock to be removed is less than two feet in depth,

but, where the depth of cut is greater than two feet, drilling and blasting by the American method is the most rapid and economical. In rock that is thinly stratified or that shatters readily, the limit of two feet for the economic use of the Lobnitz cutter may be somewhat increased.

Dredging the Broken Rock.—The choice of a dredge for the removal of the rock, broken or blasted as above, lies between the dipper and the ladder types. Except where the rock is broken by crushers of the Lobnitz type to a depth of only two or three feet, the dipper dredge is to be preferred. Its ability to handle great masses by virtue of its larger bucket effects a considerable economy through the permission of wider spacing of drill holes. The cost of the drilling and blasting is usually the largest part of the total cost of the rock removal. The smaller dimensions of the buckets of the elevator dredge require the rock to be broken into smaller fragments. The larger pieces are ejected, requiring subsequent removal by a grapple machine or other means. The ability of the ladder type to dig uniformly to grade, however, renders it particularly adaptable to the removal of rock prepared by the Lobnitz machine.

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